Tuning Control for Debutanizer Column

PREPARED BY:

Muhammad Aiman Afif Bin Muhammad Wazir

14613

SUPERVISOR:

Nasser B M Ramli

Dissertation submitted in partial fulfillment of the requirement for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

FYP II Sept 2014

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh,
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Tuning Control for Debutanizer Column

By

Muhammad Aiman Afif Bin Muhammad Wazir

14613

A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL)

Approved by,

____
(Nasser B M Ramli)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh,
Perak Darul Ridzuan

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD AIMAN AFIF BIN MUHAMMAD WAZIR

Table of Contents

List of Table

List of Figures

ACKNOWLEDGEMENT

First of all, I would like to take this opportunity to express my utmost thankfulness to Allah S.W.T whom have gave this priceless opportunity and a clear way for me to complete Final Year Project II. I thank my parents, Muhammad Wazir Bin Mohd Yusof and Norziha BT Ismail who are very supportive and caring to me in completing the projct. I would like to express my greatest appreciation to my supervisor, Mr Nasser B Ramli. He is giving me endless support and esteemed guidance throughout completion of project and without him, I am might not be able to complete this project successfully. Many thanks to the coordinator of the course, Dr Asna which has helped in me in many ways during the project and provided useful adjunct lectures that was very helpful in completing the report for the project. Lastly greatest appreciation to Universiti Teknologi PETRONAS because have give me a chance to me to complete Final Year Project and finished my undergraduate studies.

ABSTRACT

The performance of various conventional control strategies was compared against the self tuning Proportional Integral Derivative (PID) controller which examined when been applied in composition control of a debutanizer column. Tuning of PID control strategies studied and analyzed included Smith Predictor control, Internal Mode control, Cascade control, Feedback control and Feedforward-feedback control. The comparisons were done by MATLAB Simulation using Identification Tool (IDENT) and SIMULINK. The comparison for each control strategy performance was studied in terms of response towards set point changes and disturbance rejection towards error, manipulated variable which is valve opening and the scope. The success of control strategies are determined by the stability of the process model obtained from each control strategies.

CHAPTER 1: INTRODUCTION

1.1 Background

Yasuki et al (2008) stated that the PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. Its early implementation was in pneumatic devices, followed by vacuum and solid state analog electronics, before arriving at today's digital implementation of microprocessors. Jing (2001) claimed that in process control today, more than 97% of the control loops are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used.

The controllers come in many different forms. There are standalone systems in boxes for one or a few loops, which are manufactured by the hundred thousand yearly. PID control is an important ingredient of a distributed control system. The controllers are also embedded in much special purpose control systems. PID control is often combined with logic, sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing. Many sophisticated control strategies, such as model predictive control, are also organized hierarchically. The ability of PID control mode to compensate most practical industrial process has led to their wide acceptance such as in pulp and paper industries **(Astrom 2002).**

1.2 Problem Statement

Although PID controllers are the most widely used control mechanism in the world, they are also the most basic. Therefore, PID controllers are significantly limited in their capabilities, especially when complex processes are required to perform a task. PID controllers are only capable of measuring varying inputs and calculating the difference between them. Because of this, some subject specific industries must use larger and/or more expensive controllers. PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control set point value. They also have difficulties in the presence of non-linearity may trade-off regulation versus response time, do not react to changing process behavior and have lag in responding to large disturbances.

1.3 Objective

This study will be conducted to compare different advanced control strategies in tuning controller method in debutanizer column and select the best control strategy among them. The comparisons were done by MATLAB simulation to evaluate the performance of the controllers in terms of response towards set point changes and disturbance rejection, and also the opening valve which represented by Manipulated Variable.

1.4 Scope of Study

Performance of each control strategies for self tuning in debutanizer column will be studied and analyzed. The control strategies including Smith Predictor control, Internal Mode control, Cascade control, Feedback control and Feedforward-feedback control which will be tuned using Genetic Algorithm (GA). Different type of parameters will be applied to measure the performance of the control strategies including flow rate, level, temperature, pressure, error, manipulated variable which is valve opening and scope.

CHAPTER 2 : LITERATURE REVIEW AND THEORY

2.1 PID Controller

Hale (1995) stated that a proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

A typical structure of a Proportional Integral Derivatives (PID) control system is:

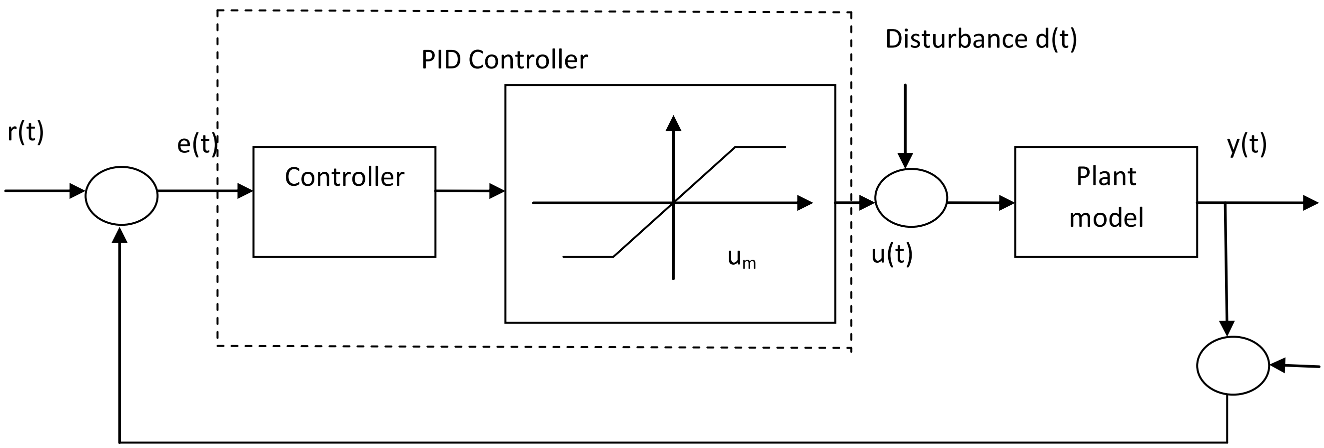


Figure 1: PID Structure

PID Algorithm and mathematical description of PID controller:

$$U(t) = K\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau t + T_d\frac{de(t)}{dt}\right]$$

(Astrom 2002)

Where y is the measured process variable, r the reference variable, u is the control signal and e is the control error $(e = y_{sp} - y)$ .The reference variable is often called the set point. The control signal is thus a sum of three terms: the P-term which is proportional to the error, the I-term which is proportional to the integral of the error, and the D-term which is proportional to the derivative of the error. The controller parameters are proportional gain *K*, integral timeT_i, and derivative time T_d **(Astrom 2002).**

2.2 Tuning of PID

Muzidah et al (2012) stated that conventional controller design methods will produce constant coefficient algorithms based upon an assumed linear time-invariant system. More systematic approaches has been studied and developed by applying various optimization techniques such as Genetic Algorithm, Particle Swarm Optimization, Bacterial Foraging Optimization and Stochastic Algorithms. The basis of a self tuning system is an algorithm that will automatically change its parameter to meet a particular requirement or situation. This is achieved by the addition of mechanism which monitors the system and adjusts the coefficient of the corresponding controller to maintain a required performance.

The ability to adapt with process variations such as load changes and disturbances has made self tuning PID an excellent alternative to the conventional method.Explicit self-tuning control (STC) use the information from model parameters that must be updated recursively in order to synthesized a new controller parameters based on specified design requirements. In some self-tuning controller, the recursive process estimation was not necessary. This type of controller is referred to as implicit self-tuning controller. Explicit STCs apply certainty equivalence principle where model uncertainties during parameter estimation were not considered. It is assumed that these values correspond to their actual values (Muzidah et al 2012).

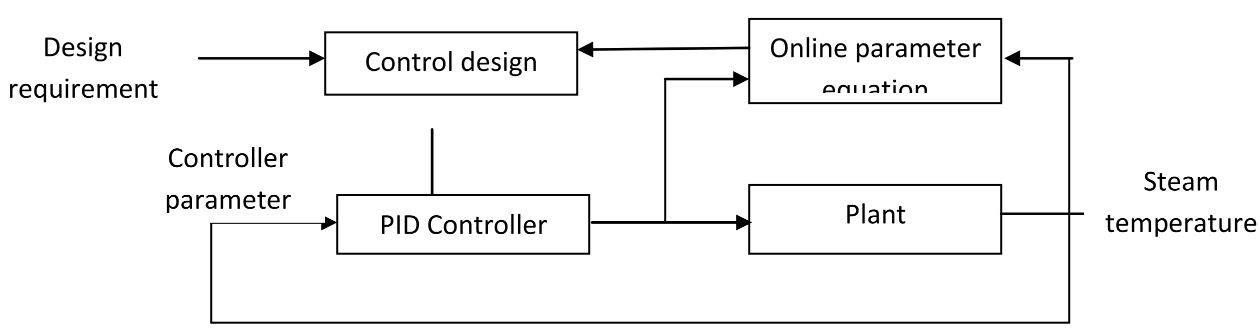


Figure 2: Explicit self tuning control structures

2.3 Smith Predictor (Dead-time Compensation)

Processes that contain a large transport lag can be difficult to control because a disturbance in set point or load does not reach the output until unit of time elapsed. Dead time compensation or also known as Smith Predictor, attempts to reduce the deleterious effect of transport lag (Donald et al 2009). The Smith Predictor is a model based controller that is effective with long dead time which has inner loop with main controller that can be simply designed without the dead time (Hang 1994). The effects of load disturbance and modeling error are corrected through an outer loop and this predictor also can be used for processes with significant non minimum phase dynamics and for high order systems that exhibit apparent dead time.

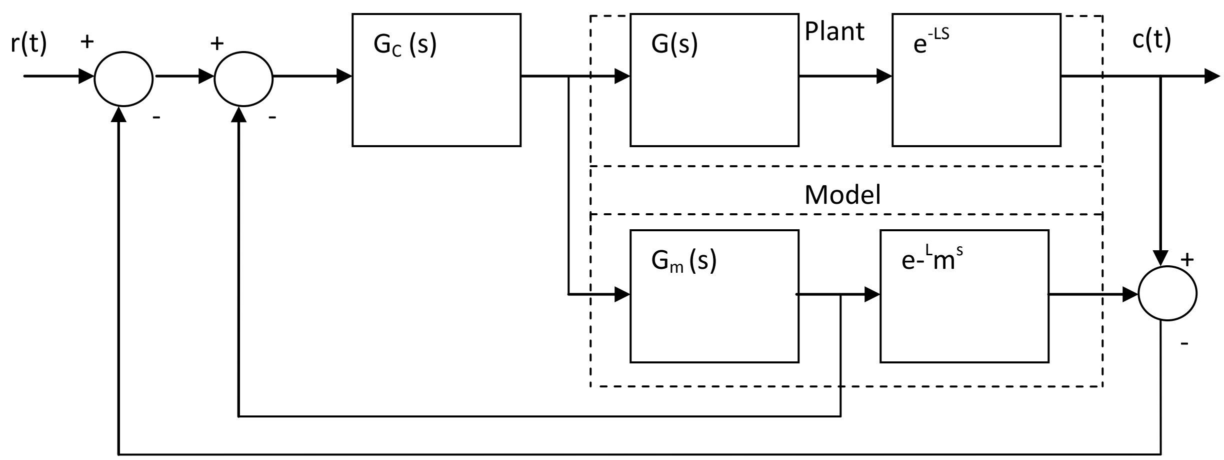


Figure 3: Smith Predictor Control Scheme

Smith Predictor as shown in Figure 4 is well known as effective dead-time compensator for a stable process with long time-delays. Ibrahim (2002) stated that while the Smith predictor structure provides a potential improvement in the closed loop performance over conventional controllers for stable processes, the structure cannot be used to control open loop unstable processes.

2.4 Internal Mode Control (IMC)

Donald et al (2009) stated that Internal Mode Control (IMC), which is based on an accurate model of the process, leads to the design of a control system that is stable and robust. A robust control system is one that maintains satisfactory control with changes in dynamics of the process (Donald et al 2009). Tien-li et al (2010) stated that Internal model-based control (IMC) has been shown to possess many advantages over PID control, particularly in the presence of significant process dead time. Implementation of IMC is simplified in a large class of industrial applications where the process dynamics can be adequately characterized by a simple first-order model requiring only estimates of process gain, lag time constant, and dead time for implementing the controller design (Tien-li et al 2010).

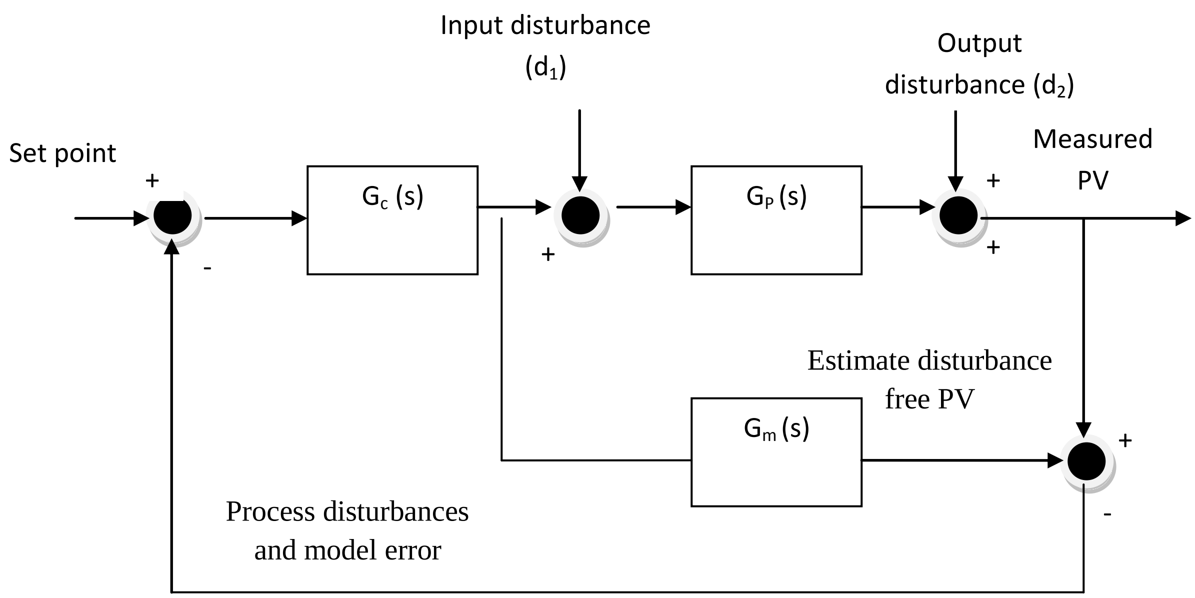


Figure 4: Internal Model Control diagram

Donald (2002) proposed that in applying IMC control system design, the following information must be specified:

- Process model
- Model uncertainty
- Type of input (step, ramp)
- Performance objective (Integral square error, overshoot)

Based on Figure 5, for an IMC-based control system, an internal model of the process is built into the controller structure. The CO that is sent to the process is also used by the model to predict the future process output (PV). To simplify the design implementation, the mathematical model used is often a lower- order parametric model for example, a first-order model where only model gain, model lag time constants, and model dead time are needed. The difference between the measured PV and the model output signal represents an estimate of the overall system disturbances including not only the actual physical disturbances affecting the process but also the effects of model inaccuracies and measurement errors (Tien-li et al 2010).

2.5 Cascade Control

Jeng et al (2012) stated that cascade control is one of the most successful control structures for enhancing single-loop_control performance, and particularly when the disturbances are_associated with the manipulated variable. Therefore, cascade control has been applied extensively in chemical process industries (Jyh 2014). The standard cascade control approach is to nest one feedback loop inside another feedback loop using two controllers. The controller of the inner loop is called the secondary controller, whereas the controller of the outer loop is the primary controller. The rationale behind this configuration is that the fast dynamics of the inner loop will enable faster disturbance attenuation and minimize the possible effect of the disturbances before they affect the primary output, which is the controlled variable of interest (Jeng et al 2012).

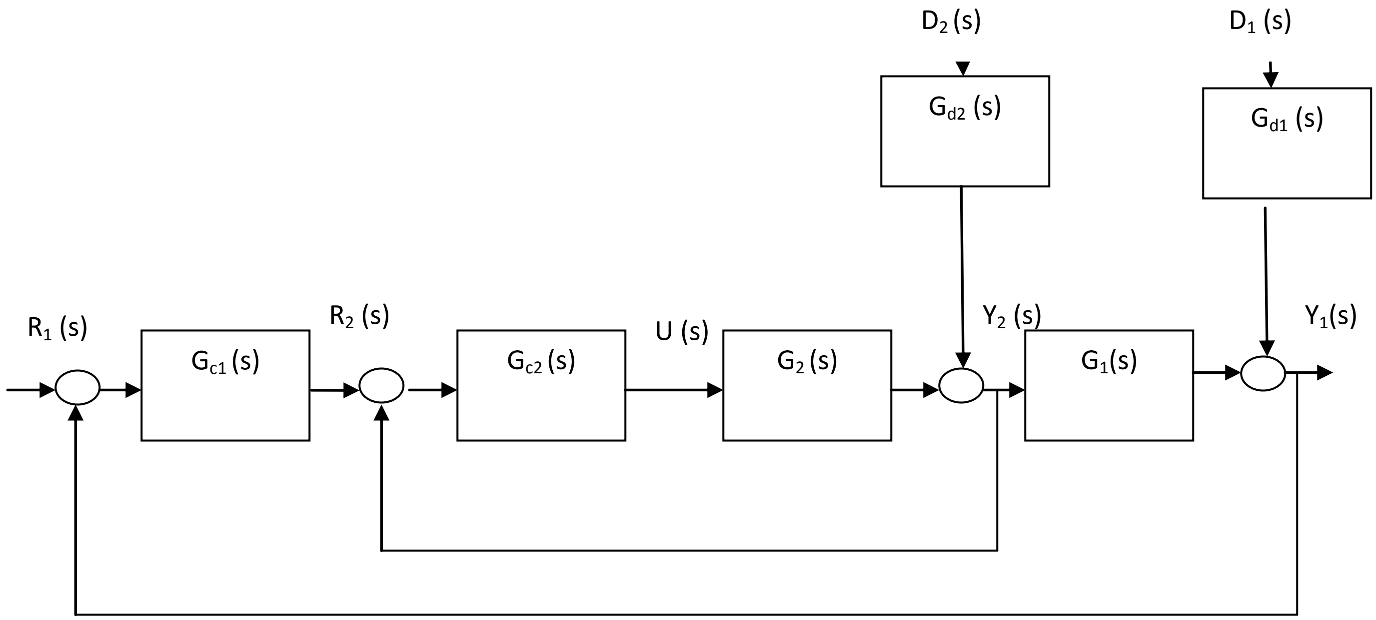


Figure 5: Configuration of Typical Cascade Control System

According to Jyh (2014), in a cascade control scheme, the introduction of an additional sensor creates a secondary (inner) loop that effectively attenuates disturbances. Figure 5 shows the configuration of a typical cascade control system, where $G_1$is the primary process and $G_2$is the secondary process. The primary controller G_c 1uses the primary process variable y_1 with set-point r_1 to establish the set point r_2 for the secondary controller G_{c2}. The secondary process variable y_2 is transmitted to the secondary controller, which adjusts the manipulated variable u. Disturbances can enter at two possible points, $d_1$and d_2, with disturbance transfer functions G_{d1}andG_{d2}, respectively. A cascade control scheme is effective because the disturbance d_2 affecting the inner loop is promptly compensated before it affects the primary process variable $y_{1.}$

2.6 Feedback and Feedforward-feedback Control System

According to Donald et al (2009), feedback control is control strategy when the manipulated variable is adjusted based on the measurement of the controlled variable (CV). It is important to make a distinction between negative feedback and positive feedback. Advantages of using feedback control strategy are corrective action is taken regardless of the source of the disturbances and it reduces sensitivity of the controlled variable to disturbances and changes in the process. Besides, it is simple to implement and also requires minimal detailed information about how the process itself works. Feedback control action is entirely empirical thus as long as an adjustment is being made in the correct sense then the control system should remove the effect of an external disturbance.

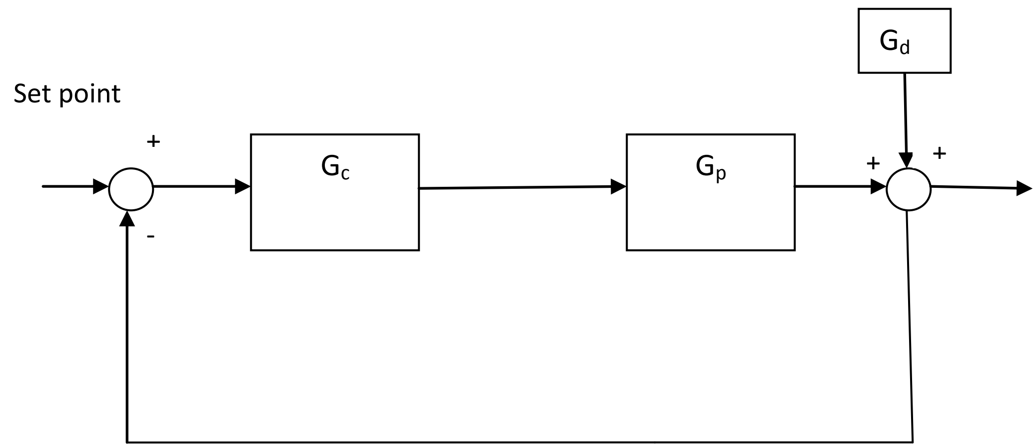


Figure 6: Feedback Control Loop

Donald et al (2009) also stated that feedforward control strategy is control strategy where the manipulated variable is adjusted based on the measurement of the disturbance variable (DV). In some cases the major load disturbance to a process may be measured and utilized to provide feedforward control. Advantages of using feedforward control strategy are it takes corrective action before the process is upset and does not affect system stability. The disadvantages of this control strategy are disturbance must be measured for example capital and operating costs, and requires more knowledge of the process to be controlled. Feedforward control is usually used in conjunction with feedback control to improve disturbance rejection. The strategy control called Feedforward-feedback control.

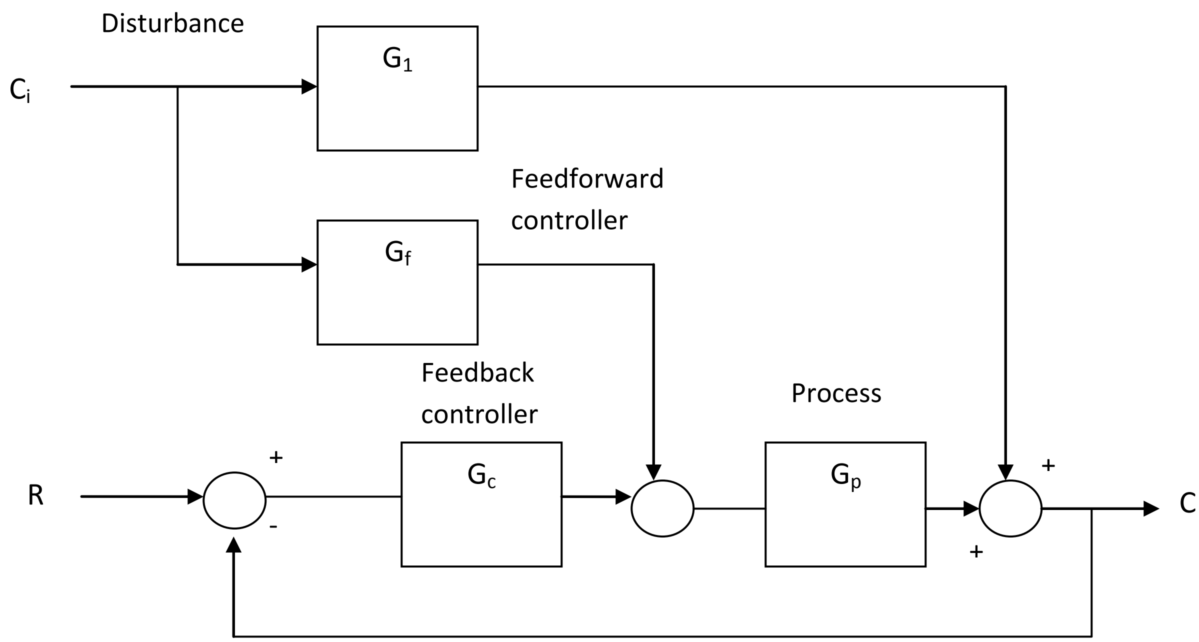
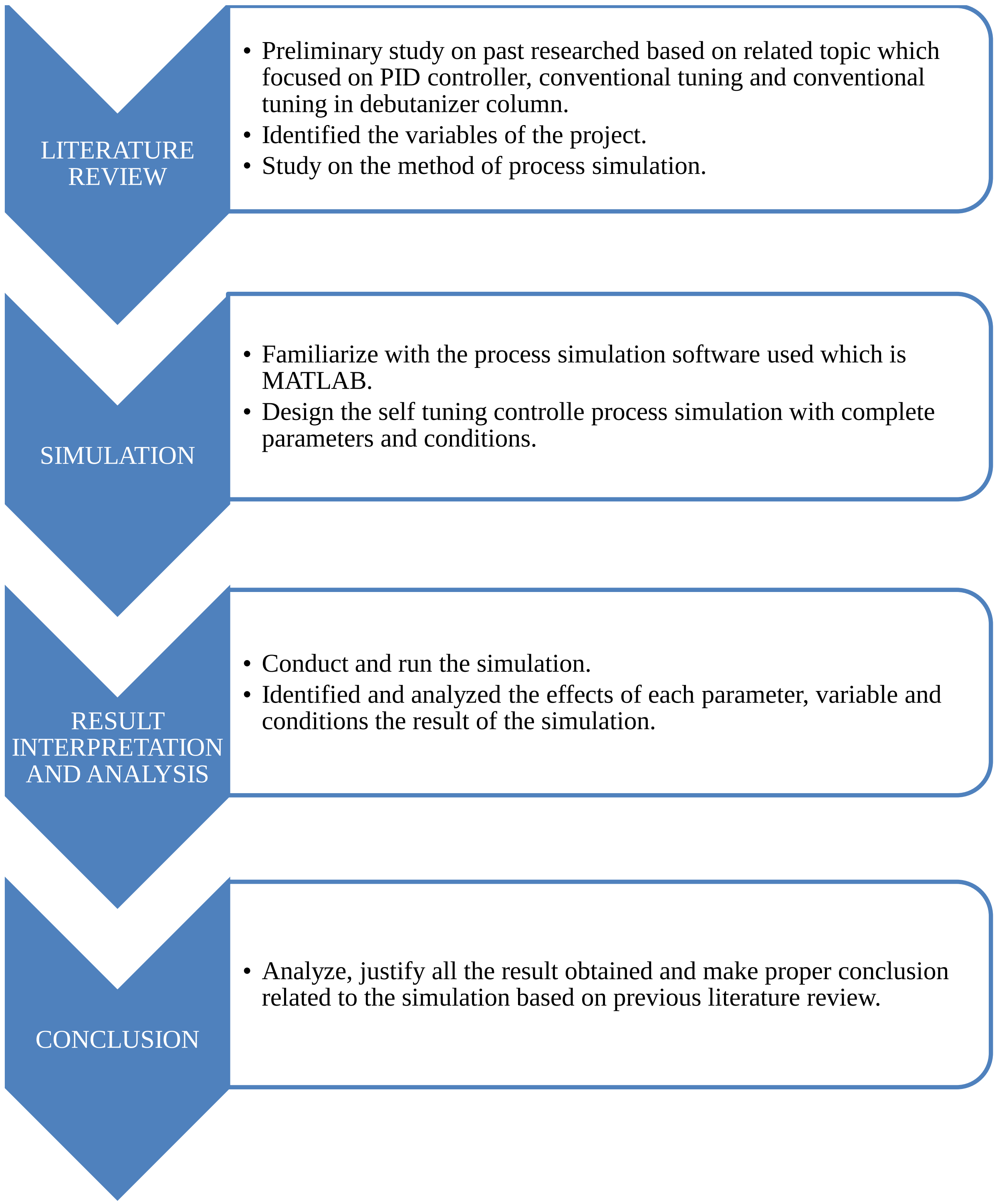


Figure 7: Feedforward-feedback Control Loop

CHAPTER 3: METHODOLOGY

3.1 Project Flow Chart



3.2 Project Methodology (MATLAB Simulation)

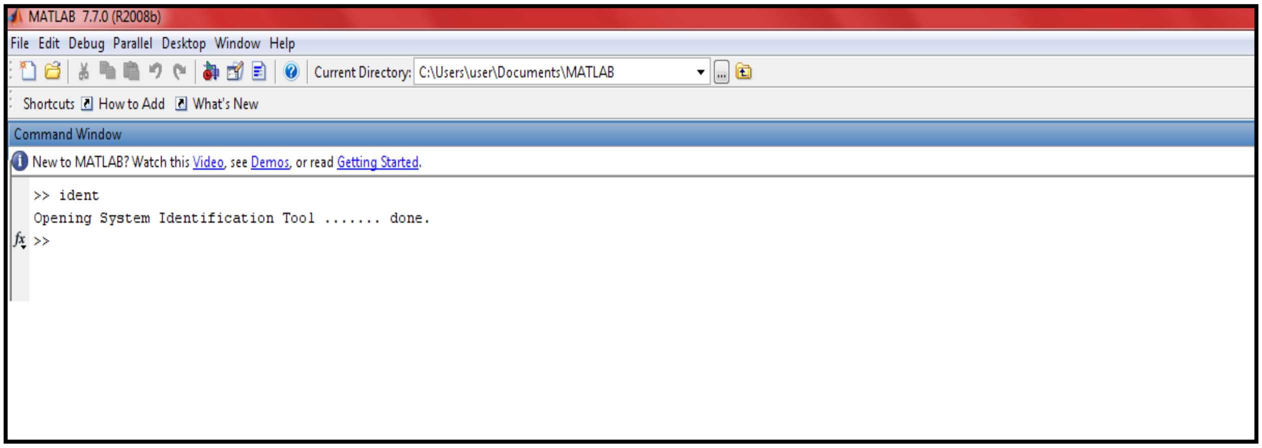


Figure 8: MATLAB Interface

MATLAB Simulation was used to study each control strategy performance in terms of set point regulation, response towards set point changes and disturbance rejection. After MATLAB program has been opened, in the command window, IDENT this stands for Identification Tools opened.

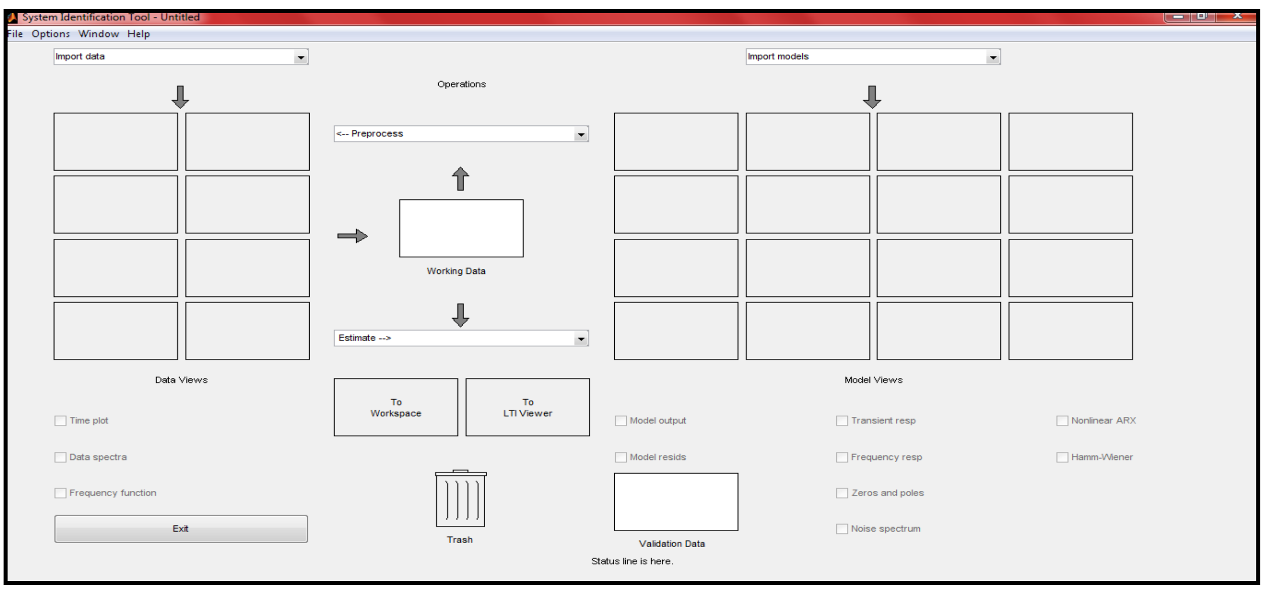


Figure 9: IDENT Interface

This is the main interface in System Identification Tools which will be used in determining the most stable and high performance of process models for each parameter including flow rate, level, pressure and temperature.

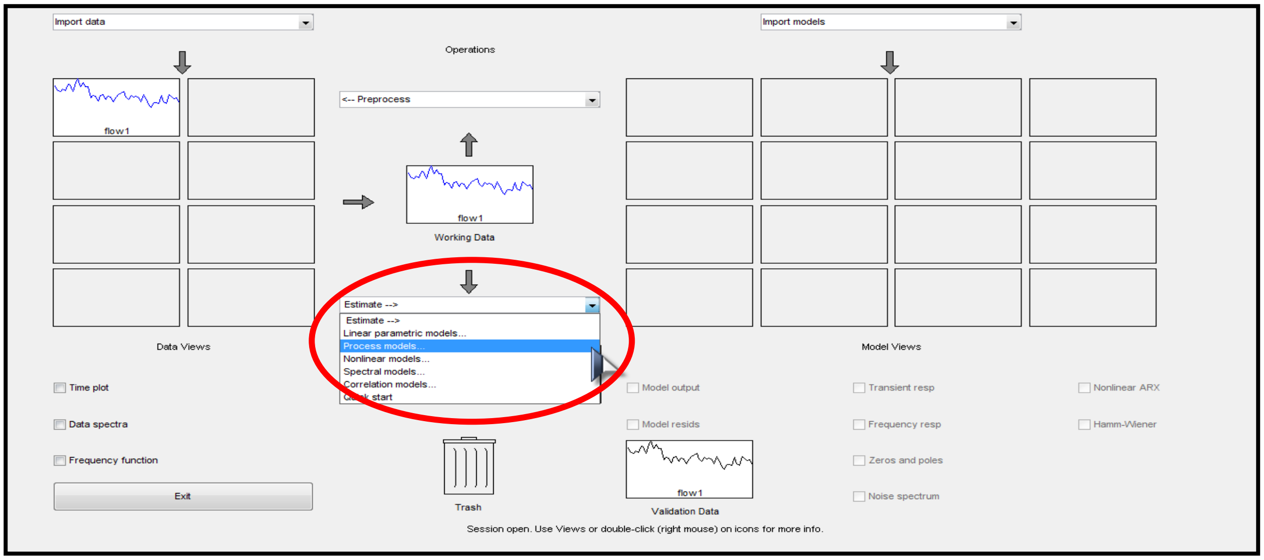


Figure 10: Process Models Selection

In IDENTt, as showed at Figure 10, at Estimate options, Process Models was chose in order to determine the best process model for each control strategies.

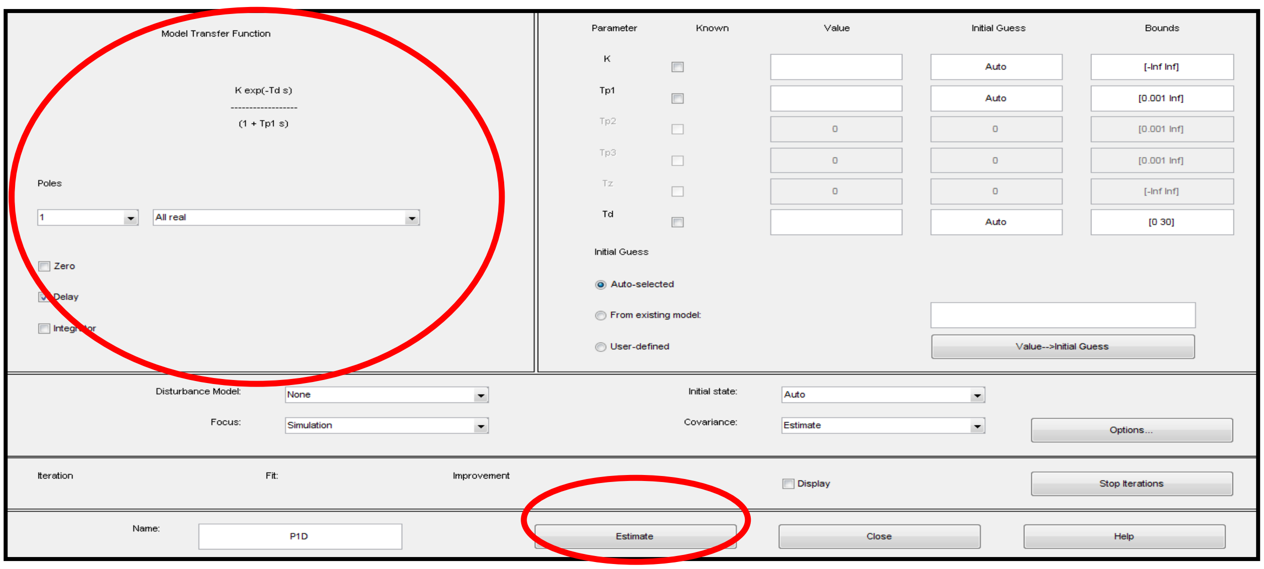


Figure 11: Estimation of Transfer Function

After Process Models has been chosen, this is the main interface of Process Models criteria selection. In this interface, there are stated Main Transfer Function and Poles options. In Poles options, number of poles has to be selected and confirmed which range from 0 to 3 and also have to choose between All Real and Under damped properties. Next, for Poles properties, we have to choose between Zero order, Delay and Integrator. Next, Estimate option is choose.

Figure 12: Selection of Most Stable Transfer Function

As we can see from Figure 12, the process model already been developed, which showed in Working Data. To get the full result of stability and performance of the process model that has been generated, Model Output option is selected.

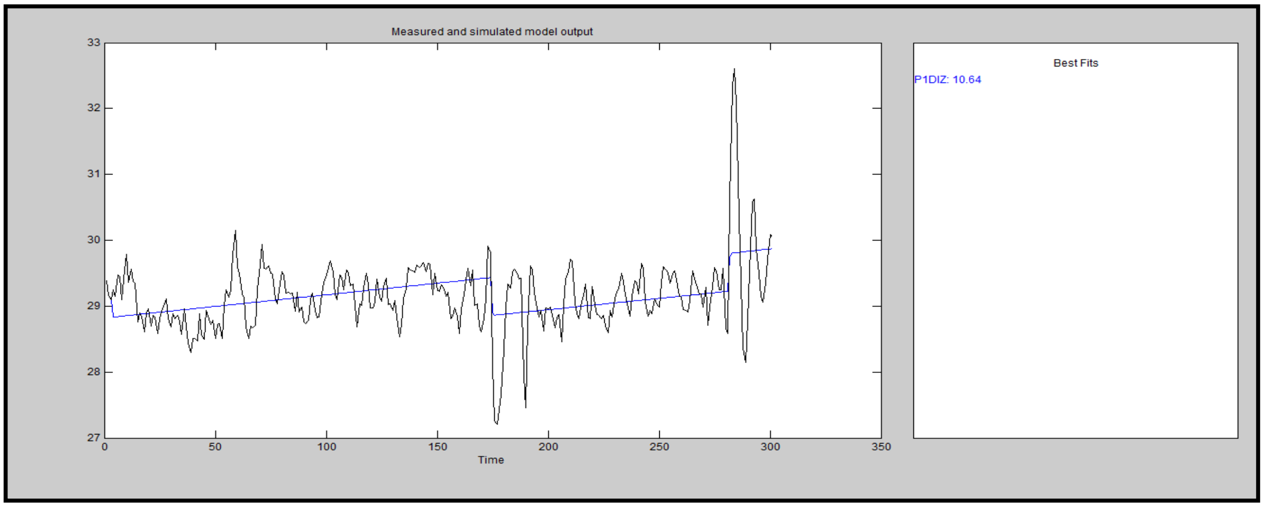


Figure 13: Value of Selected Process Models

Figure 13 showed that the value for the process models obtained is 10.64. The best and high performance of process models will be approaching positive 100. These steps were repeated until the highest value of all process models examined is obtained.

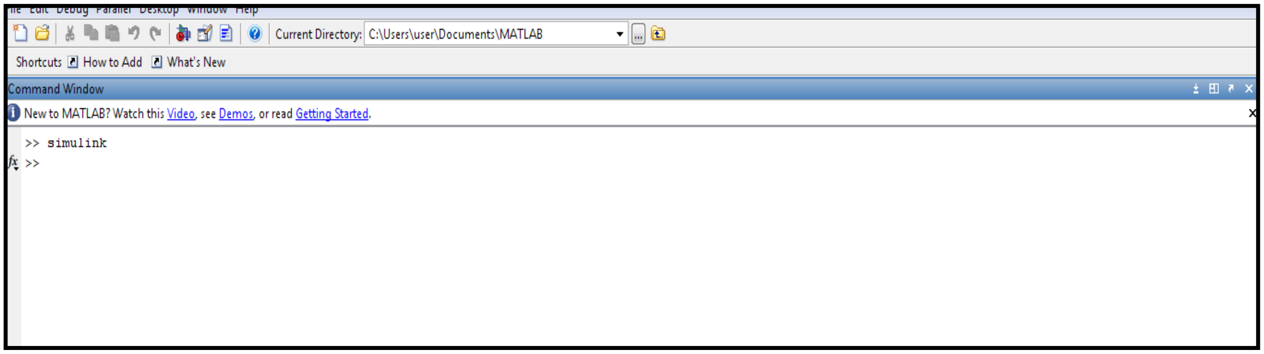


Figure 14: SIMULINK Interface

After the best process model is obtained from simulation of IDENT, SIMULINK was used to determine the best self tuning control strategy using the process models obtained. As can be seen in Figure 14, in the command window, SIMULINK function was inserted and opened.

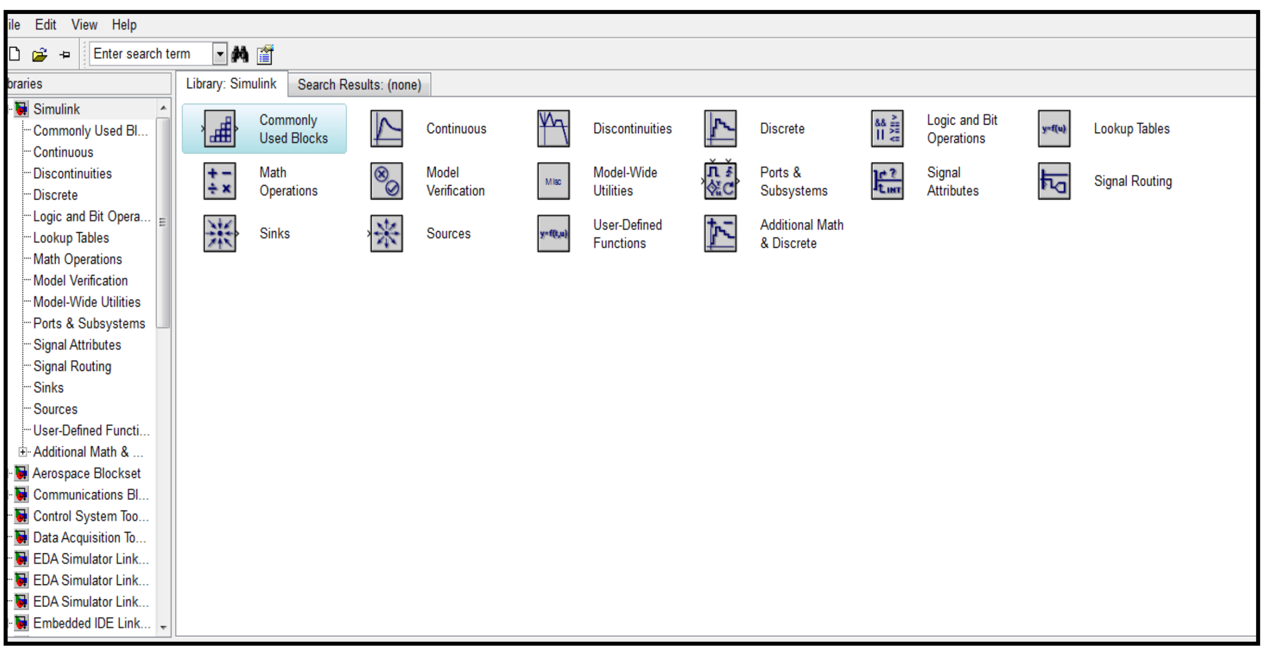


Figure 15: Startup of Block Diagram in SIMULINK

This is the main interface of Simulink function. In this section, block diagram of different control strategy will be developed to determine the most efficient and high performance in terms response towards set point changes and disturbance rejection.

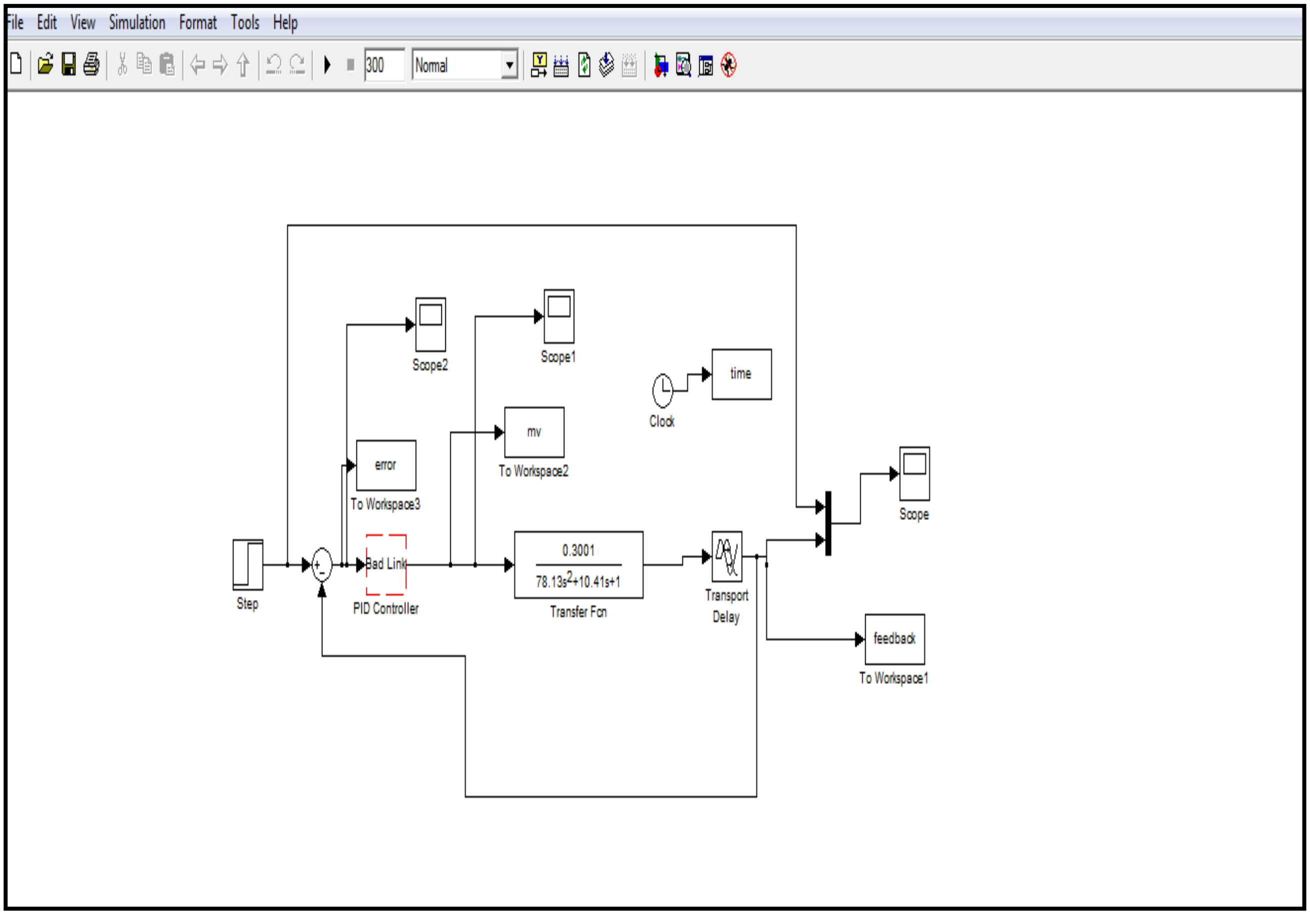


Figure 16: Example of Block Diagram

This is one of the examples of block diagram generated from process models obtained. In **Figure 16**, the block diagram been developed is for **Feedback Control strategies**. Thus, this step will be repeated for all stated control strategies which included Smith Predictor control, Internal Mode control, Cascade control, and feedforward-feedback control.

3.3 Gantt Chart and Key Milestone

No	Detail Work	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Work continue.														
2	Simulation of Stability of Transfer Function														
3	Selection of suitable Transfer Function For Each Parameter														
4	Developing block diagram in SIMULINK.														
5	Analyze and investigated the effect of step input and disturbance input towards the result.														
6	Submission of Progress Report														
7	Project Work Continues														
8	Analyze the result which covered error,														

	manipulated variable (MV) and scope.														
9	**Pre-SEDEX**														
10	Submission of Draft Report														
11	Submission of Dissertation (soft bound)														
12	Submission of technical paper														
13	Oral Presentation														
14	Submission of Project Dissertation (Hard Bound)														

CHAPTER 4: RESULTS AND DISCUSSION

	m3/hr		%		KPa	$℃$
CONTROLLERS	**FLOW 1**	**FLOW 2**	**LEVEL 1**	**LEVEL 2**	**PRESSURE 1**	**TEMP 5**
TAG NUMBER	FIC 123	FIC 126	LC 111	LC 112	PC 109	TC 110
PB	100	200	45	250	50	135.7
Kc	1.00	0.50	2.22	0.40	2.00	0.74
Ti (seconds)	30	12	660	550	42	250
Td (seconds)	0	0	0	0	0	80
Set Point, SP (m3/hr)	44.64	7.55	-	-	-	-
Set Point, SP (%)	-	-	45.88	7.6	-	-
Set Point, SP (KPa)	-	-	-	-	823.8	-
Set Point, SP ($℃$)	-	-	-	-	-	20

Table 1: Parameters involved for simulation

Using Identification Tools (IDENT) in MATHLAB, stable transfer function have been selected for each parameter considering the highest valued obtained approaching 100 units value.

4.1 Simulation of stability of Transfer Function

PARAMETER	TRANSFER FUNCTION
FLOW 1	$G(s) = \dfrac{46.28s + 3.676}{9.255s^3 + 5.281s^2 + 3.962s + 1}$
FLOW 2	$G(s) = \dfrac{-51.48s + 0.8559}{272.26s^2 + 3.679s + 1}$
LEVEL 1	$G(s) = \dfrac{0.00284}{0.8332s^4 + 1764s^3 + 100s^2 + 3.962s + s}$
LEVEL 2	$G(s) = \dfrac{-7.158s - 4323}{8.937s^2 + 1.44s + 1}$
PRESSURE 1	$G(s) = \dfrac{5105s + 107.4}{75.95s^2 + 49.3s + 1}$
TEMEPERATURE 5	$G(s) = \dfrac{1.381s + 13.89}{348.8s^2 + 137s + 1}$

Table 2: Selected Transfer Function

4.2 Simulation of Block Diagram in SIMULINK for Selected Transfer Function

In the simulation, the configuration for each PID controller for each parameter is varied as showed below, referring to the K_C value, T_i valued and T_d value.

CONTROLLERS	FLOW 1	FLOW 2	LEVEL 1	LEVEL 2	PRESSURE 1	TEMP5
Kc	1.00	0.50	2.22	0.40	2.00	0.74
Ti (seconds)	30	12	660	550	42	250
Td (seconds)	0	0	0	0	0	80

Table 3: Configuration for PID Controller

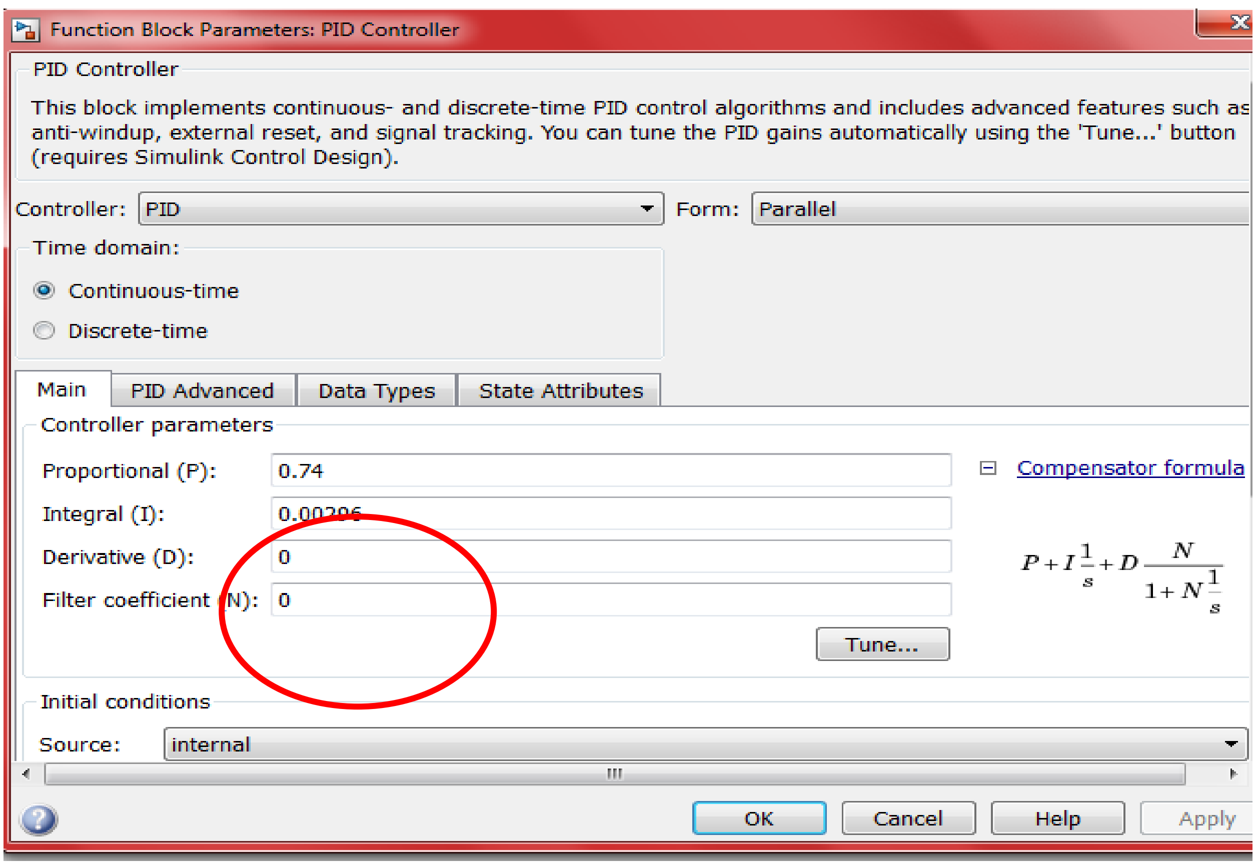


Figure 17: Interface for Configuration for PID Controller

4.2.1 Feedback control strategy

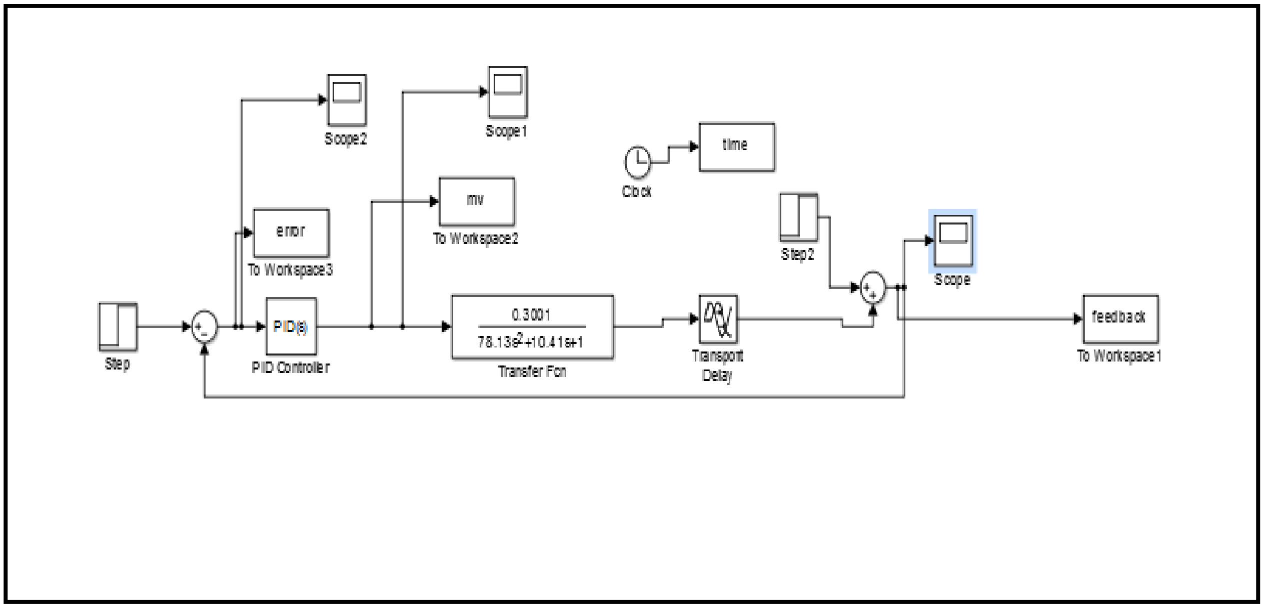


Figure 18: Step and Disturbance Input Simulation for Feedback Control Strategy

4.2.2 Feedforward feedback Control Strategy

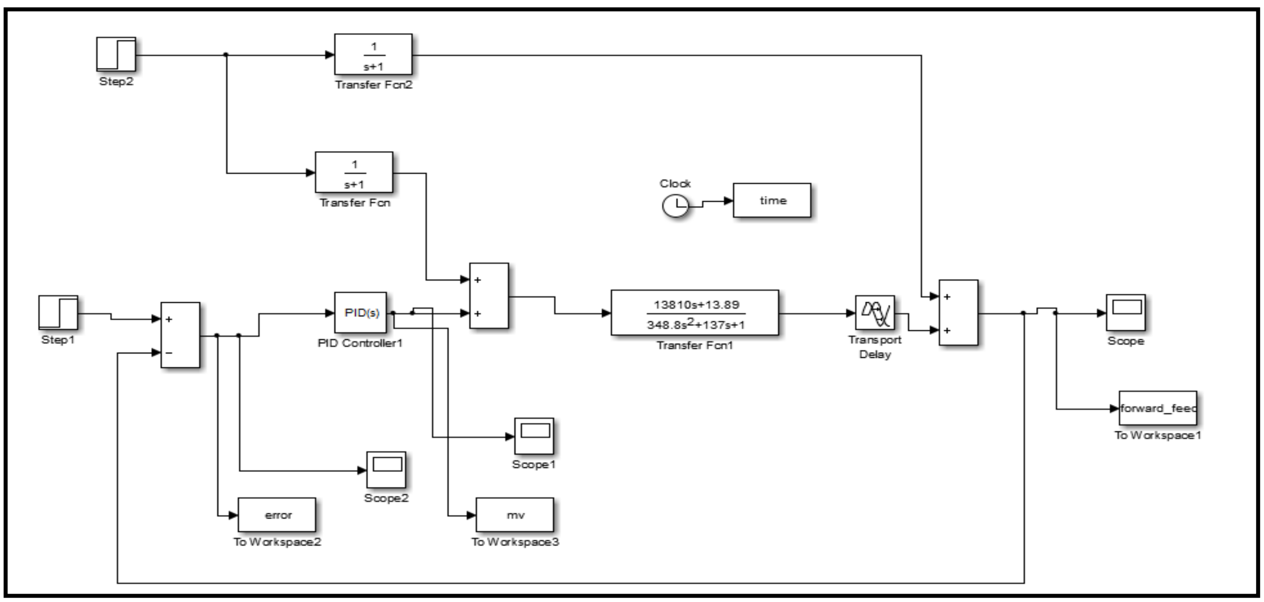


Figure 19: Step and Disturbance Input Simulation for Feedforward feedback Control Strategy

4.2.3 Smith Control Strategy

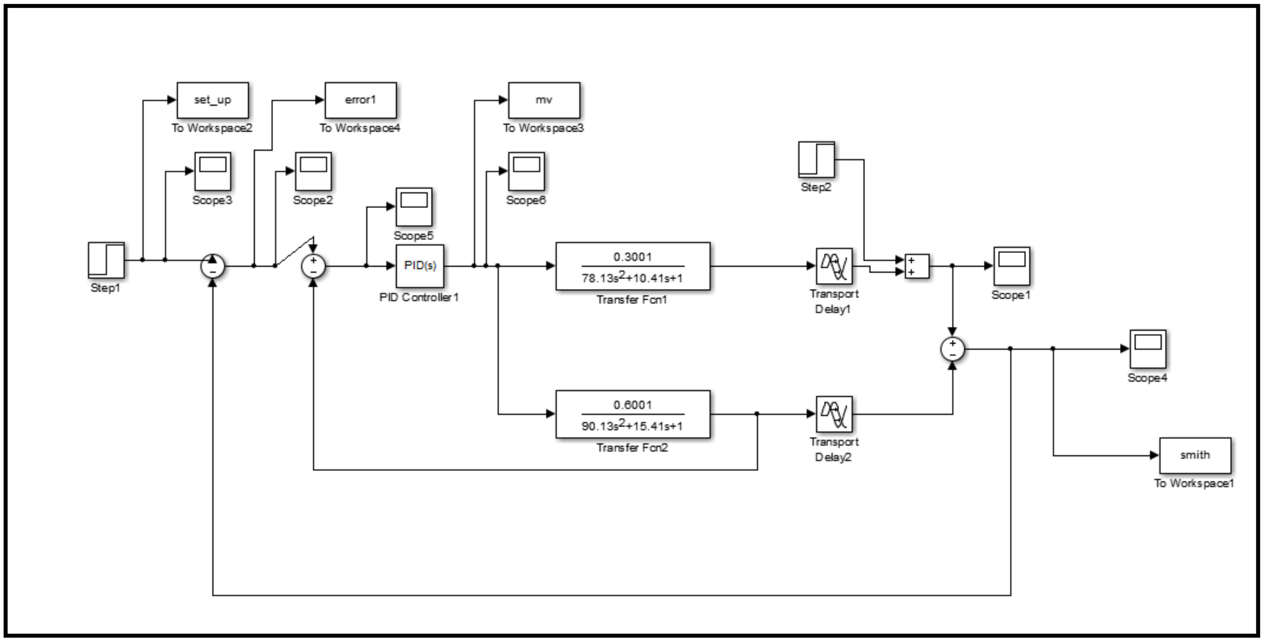


Figure 20: Step and Disturbance Input Simulation for Smith Control Strategy

4.2.4 Cascade Control Strategy

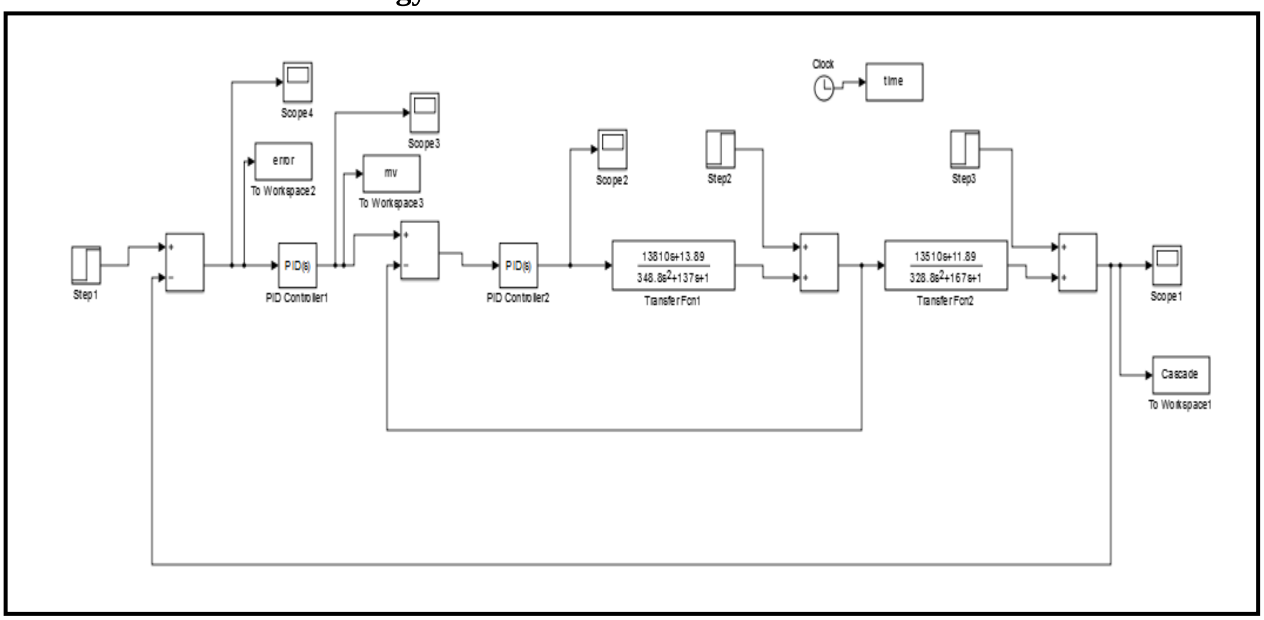


Figure 21: Step and Disturbance Input Simulation for Cascade Control Strategy

4.2.5 Internal Mode Control (IMC) Control Strategy

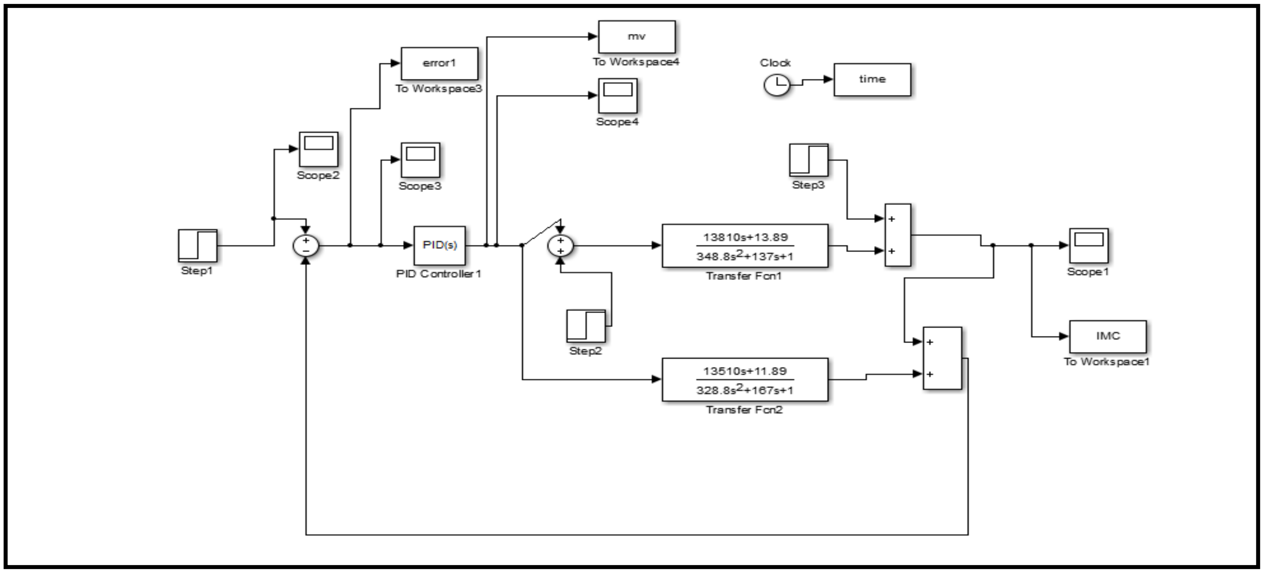


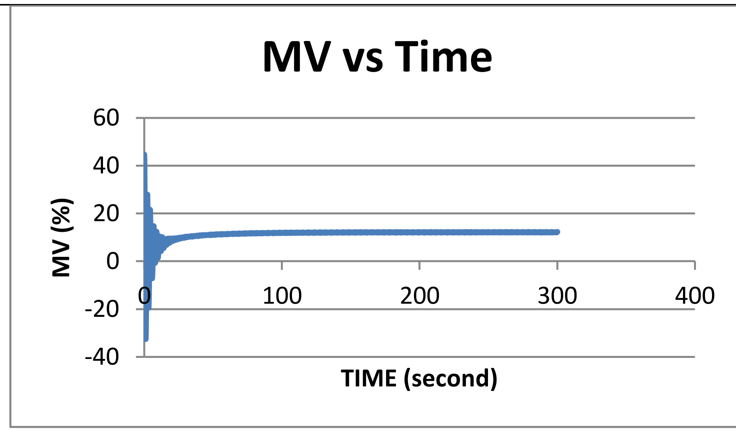
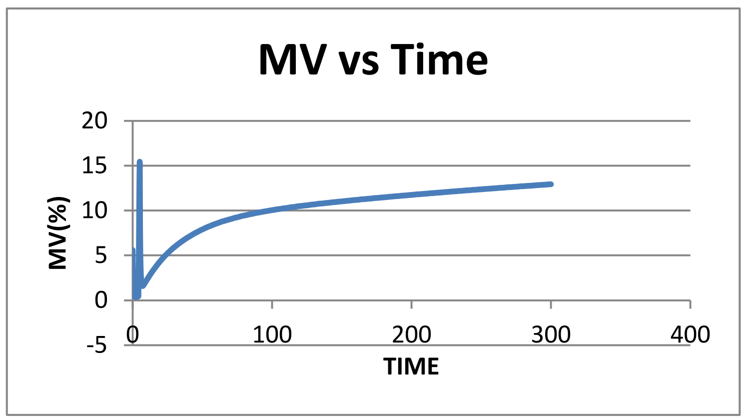
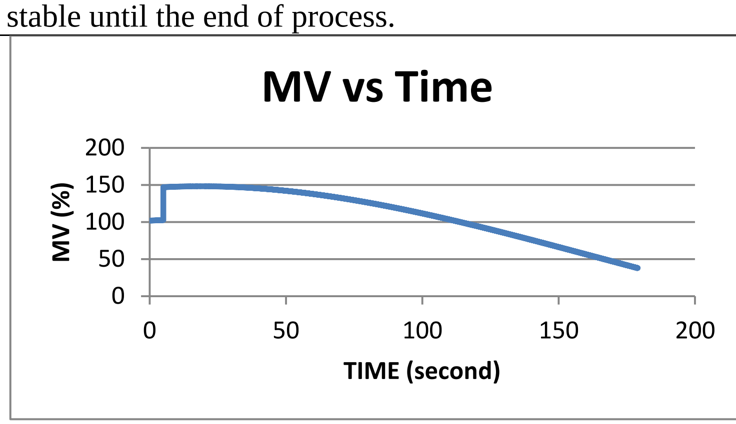
Figure 22: Step and Disturbance Input Simulation for IMC Control Strategy

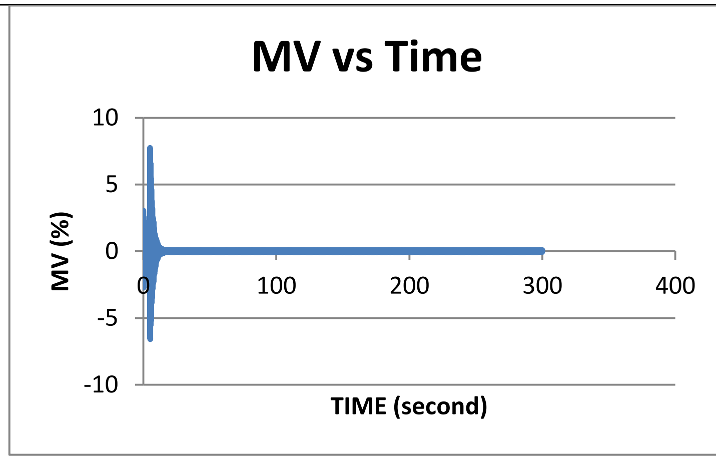
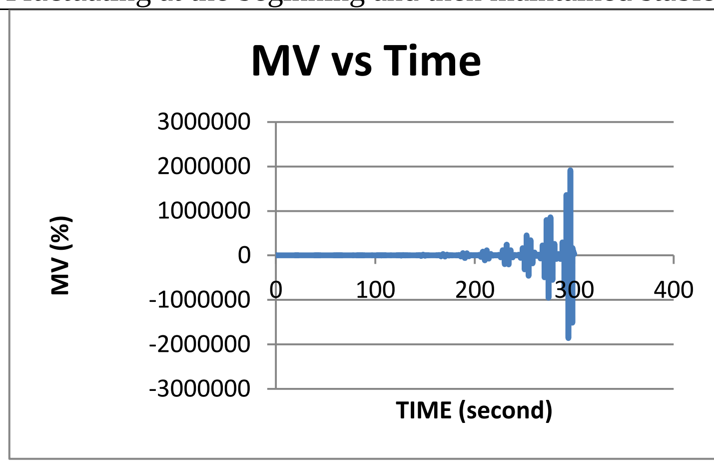
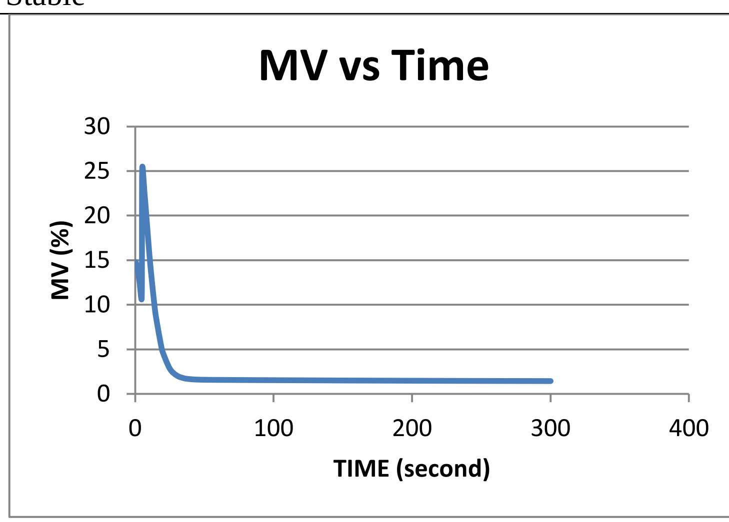
4.3 RESULTS AND DISCUSSION FOR SIMULATION IN SIMULINK

In determining and selecting the best controller for each parameter, there are 3 main criteria to be considered. The first criteria is the valve opening which represented by Manipulated Variable (MV) graph. For the best and stable condition in MV vs. Time graph, the valued should be in a range of 0 to 100, and the value also should not fluctuated much as it will reduces the performance of the valve. The next criteria are the area of error, represented by Error vs. Time graph. In the block diagram developed, error is measure before controller take place, so the value of area of error should as small as possible. The last criteria is scope which represent the overall performance of the parameter itself, which represented by Scope vs. Time graph.

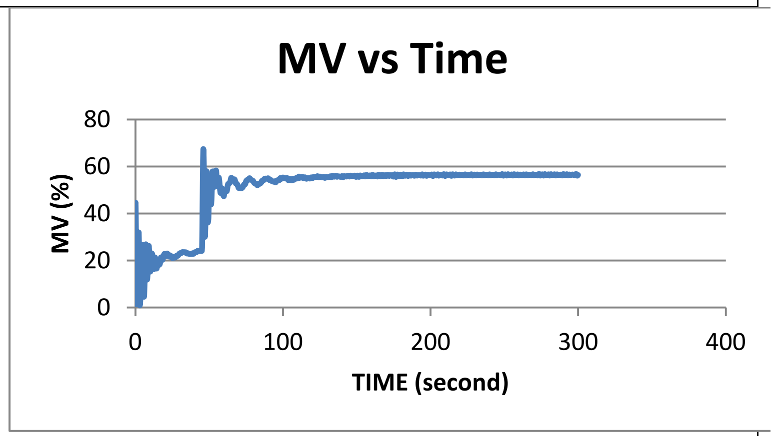
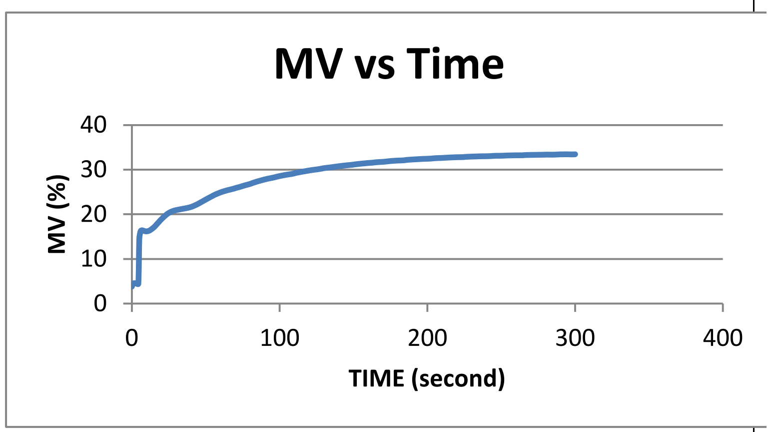
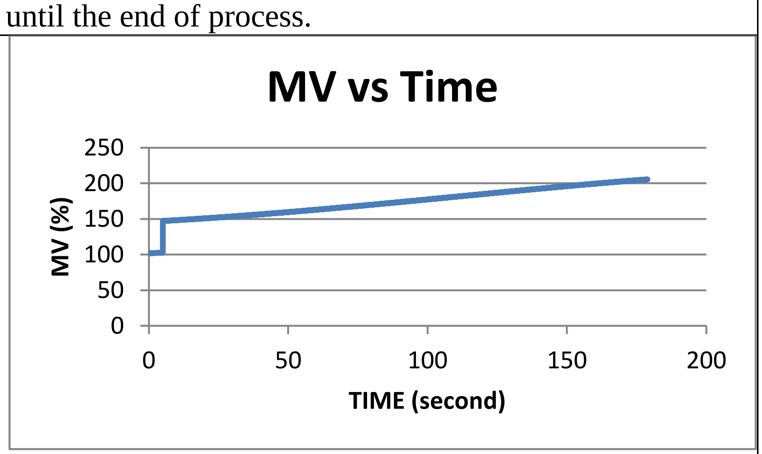
The simulation was conducted in 2 modes which the first one is in Step, where only Step 1 has the value for set point which Step 2 and Step 3 are 0. For second mode which is Disturbance, the situation is different where Step 2 and Step 3 have the value for set point, while for Step 1 the value is zero All the simulation for each control strategies for each parameter using selected stable transfer function has been successfully conducted. The full result for each control strategy is in Chapter 7 which is in appendices section.

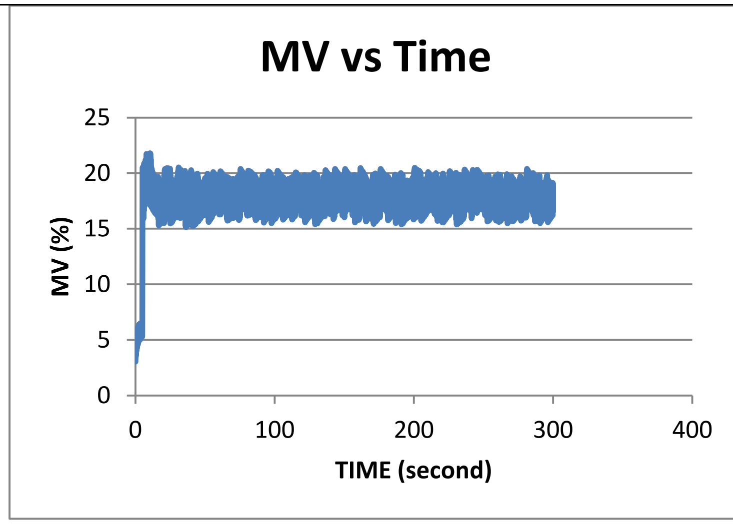
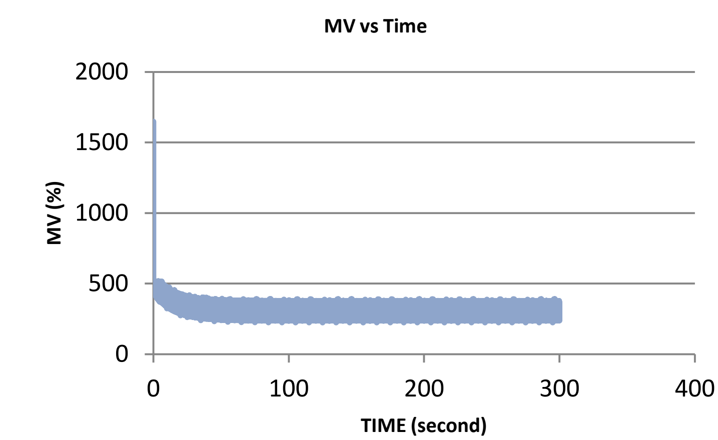
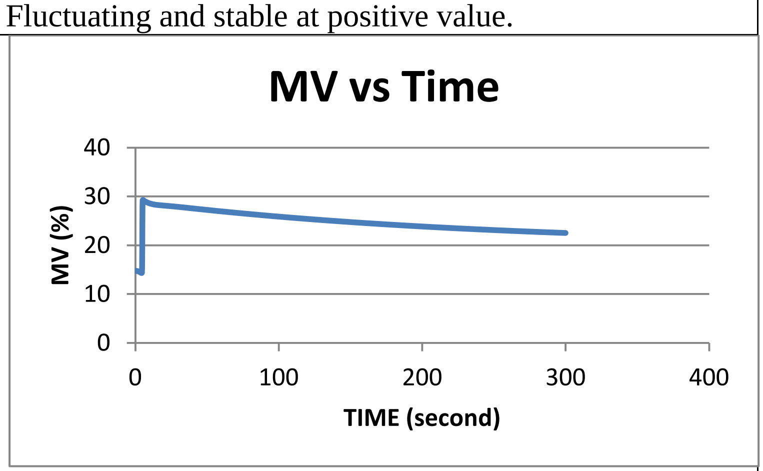
4.3.1 Best Control Strategy for Step

PARAMETER	CONTROL STRATEGY	DESCRIPTION
FLOW1	Internal Mode Control	 Area of error = 367.392 Value fluctuated at the beginning and then maintained stable until the end of process.
FLOW2	Internal Mode Control	 Area of error = 2.58E+03 Value fluctuated at the beginning and then maintained stable until the end of process.
LEVEL1	Internal Mode Control	 Area of error = 5.52E+03 Stable

LEVEL2	Internal Mode Control	 Area of error = 2.8824 Fluctuating at the beginning and then maintained stable.
PRESSURE1	Smith Predictor Control	 Area of error = 2.8824 Stable
TEMP5	Internal Mode Control	 Area of error = 458.01 Fluctuating at the beginning and then maintained stable.

4.3.2 Best Control Strategy for Disturbance

PARAMETER	CONTROL STRATEGY	DESCRIPTION
FLOW1	Internal Mode Control	 Area of error = 1.71E+03 Fluctuating at the beginning and then maintained stable until the end of process.
FLOW2	Internal Mode Control	 Area of error = 97.865 Fluctuating at the beginning and then maintained stable until the end of process.
LEVEL1	Cascade Control	 Area of error = 5.52E+03

		Stable
LEVEL2	Internal Mode Control	 Area of error = 1.03E+04 Fluctuating at the beginning and then maintained stable.
PRESSURE1	Smith Predictor Control	 Area of error = 10241.79 Fluctuating and stable at positive value.
TEMP5	Internal Mode Control	 Area of error = 5753 Stable.

CHAPTER 5: CONCLUSION

This simulation project has successfully achieved the main objective which is to compare different advanced control strategies used in tuning controller method in debutanizer column and select the best advance control among them. The comparisons has been successfully conducted using MATLAB simulation to evaluate the performance of the controllers in terms of response towards set point changes and disturbance rejection, and also the opening valve which represented by Manipulated Variable. Internal Mode Control (IMC) control strategy has been selected as the best control strategy for both Step and Disturbance mode, considered the stability and minimum value of error obtained after the complete simulation. For further action plans, more parameter and other control of strategy should be consider and study to increase the efficiency for control strategy in debutanizer column.

CHAPTER 6: REFERENCES

Muzidah T (2012). *Comparison between Optimally-tuned PID with Self tuning PID for Steam Temperature Regulation.* Shah Alam, Malaysia.

Astrom (2002). *PID Control.*

Hale H, Can E.B, Antony P W (1995). *Self-Tuning and Conventional Control of an Industrial Scale Packed Distillation Colum.* Ankara University, Faculty of Science, Chemical Engineering Department, Tandogan, Ankara, Turkey.

Danijel P, Siniša P, Davor Z (2012). *PID controller auto-tuning based on process step response and damping optimum criterion.* Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Crotia.

Yasuki K, Li J, Min SC (2007). Self-tuning PID controllers based on the Lyapunov approach. Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore.

Jing C.S (2001). *New tuning method for PID controller.* Department of Automation Engineering, National Huwei Institute of Technology, Huwei, Taiwan.

Donald R.C, Steven E.L (2009). *Process Systems Analysis and Control.* McGraw-Hills Chemical Engineering Series, Third Edition.

Hang C.C (1994).*Smith Predictor and its Modification*. Control Systems, Robotics and Automation Vol II. Department of Electrical Engineering, National University of Singapore.

Ibrahim K (2002). *Obtaining controller parameters for a new PI-PD Smith predictor using auto tuning.* Deptartment of Electrical and Electronics Engineering, Engineering Faculty, Inonu University, Malatya, Turkey.

Tien-li C, Irving L (2010). *Internal model-based control for integrating processes.* ControlSoft Inc., United States.

Jeng J.C, Lee M.W (2012*). Simultaneous automatic tuning of cascade control systems from closed-loop step response data.* Department of Chemical Engineering and Biotechnology, National Taipei University of Technology, Taipei 106, Taiwan.

Jeng J.C (2014). *Simultaneous closed-loop tuning of cascade controllers based directlyon set-point step-response data.* Department of Chemical Engineering and Biotechnology, National Taipei University of Technology, Taiwan.

Altınten A, Ketevanlioglu F, Erdogan S, Hapoglu H, Alpbaz M (2007). *Self-tuning PID control of jacketed batch polystyrene reactor using genetic algorithm.* Gazi University, Faculty of Engineering and Architecture, Department of Chemical Engineering, Ankara, Turkey.

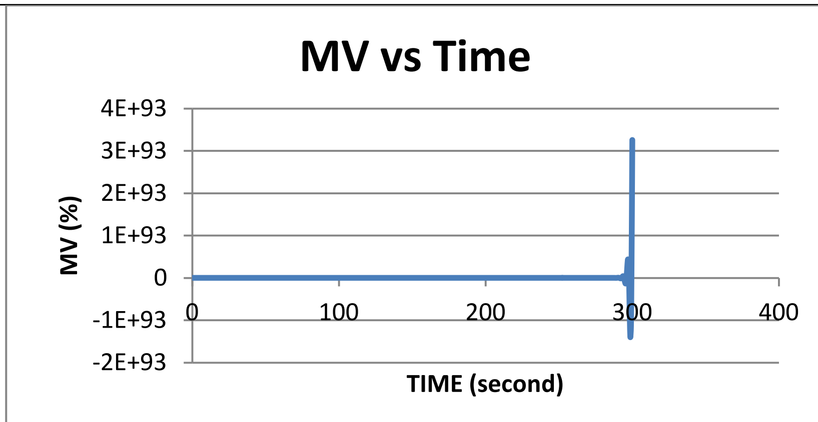
Mohideen K.A, Saravanakumar G, Valarmathi K, Devaraj D, Radhakrishnan T.K. (2012).*Real-coded Genetic Algorithm for system identification and tuning of a modified Model Reference Adaptive Controller for a hybrid tank system.*

CHAPTER 7: APPENDICES

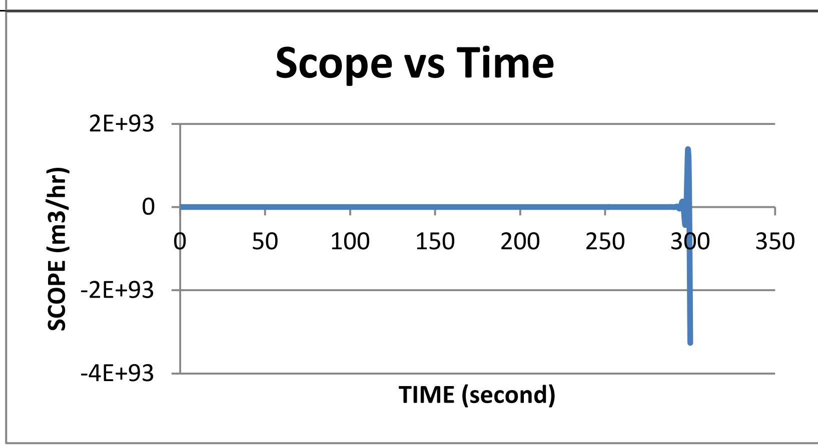
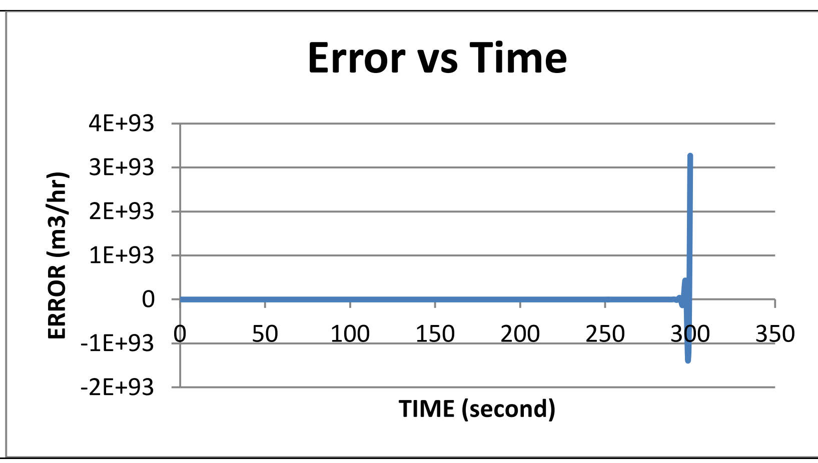
7.1 Disturbance

7.1.1 FLOW1

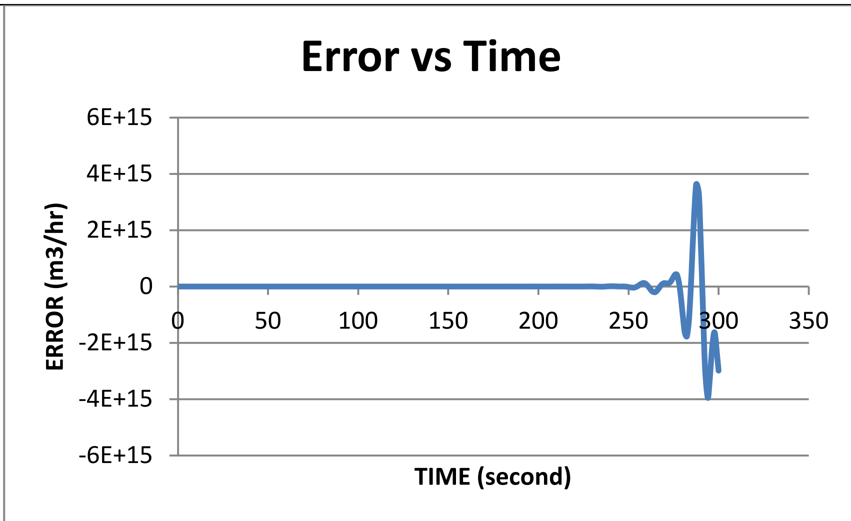
- Cascade control

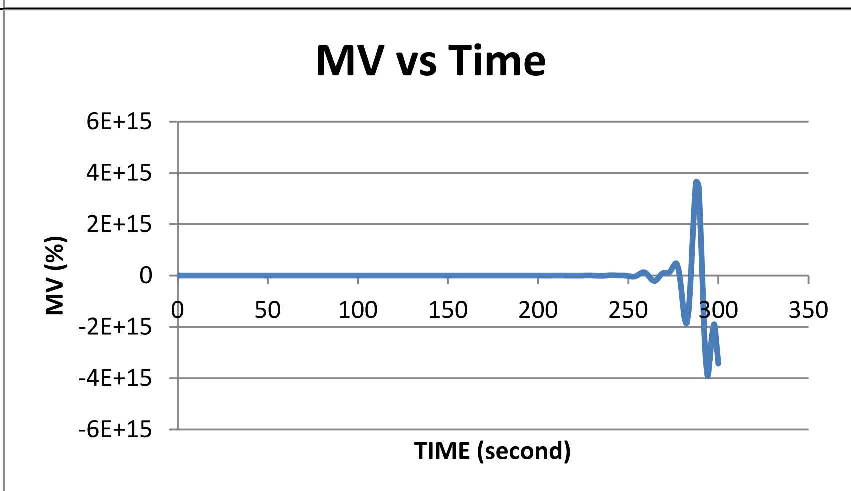
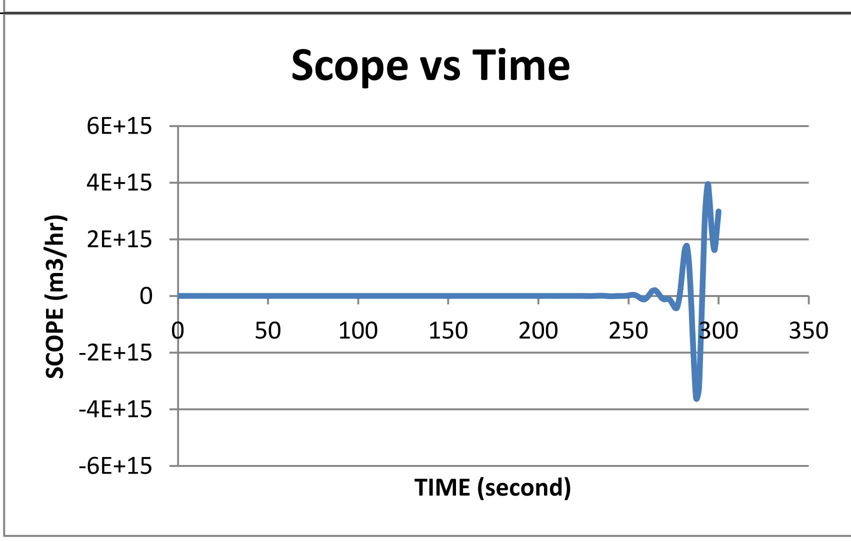
<table>
<tr>
<td>
</td>
<td>Area of error =

9.59E+91

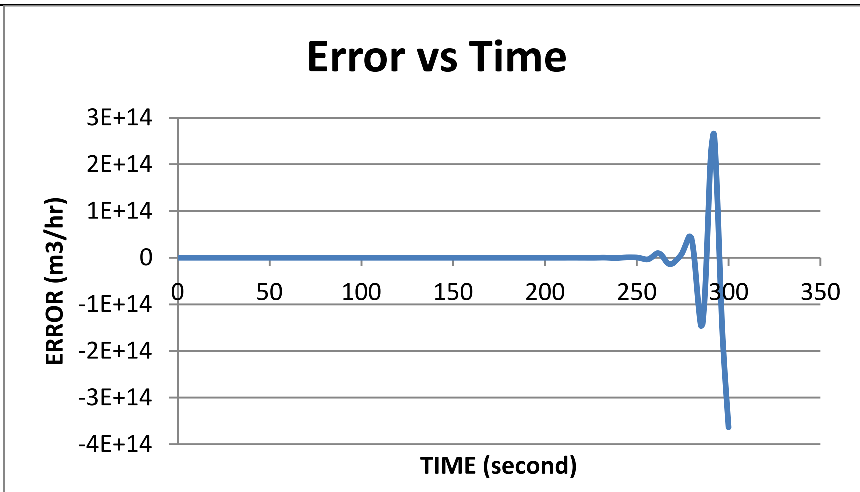
Maintained stable at the beginning at the value of 0 and began increasing drastically at short time.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the beginning at the value of 0 and began decreasing drastically at short time.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the beginning at the value of 0 and began increasing drastically at short time.</td>
</tr>
</table>

- Feedback Control

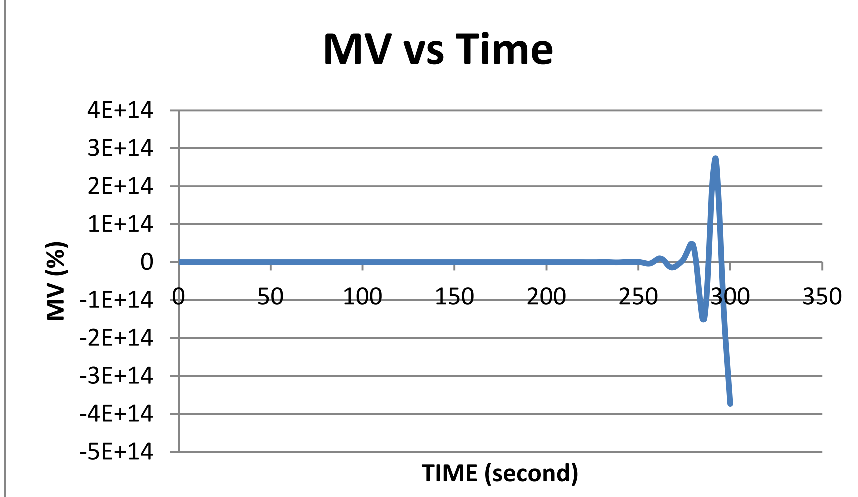
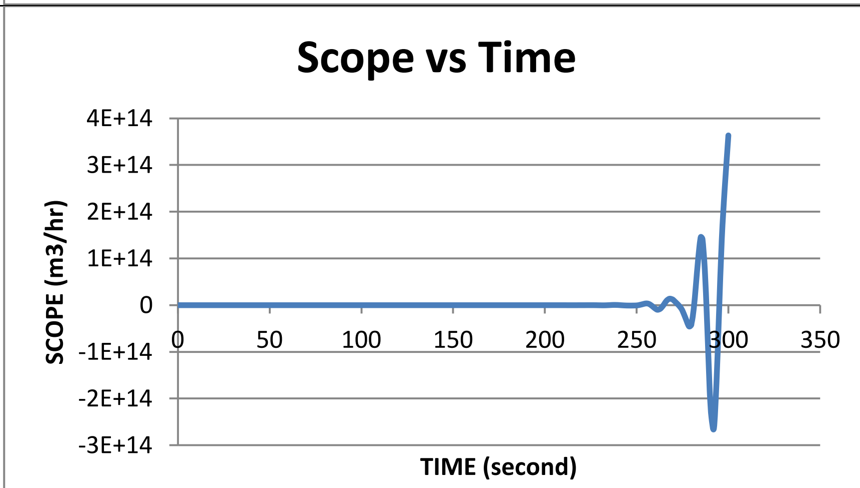
<table>
<tr><td>
</td><td>Area of error:
1.36E+16

Maintained stable at the beginning at the value of 0 and began fluctuating at the end.</td></tr>
<tr><td>
</td><td>Maintained stable at the beginning at the value of 0 and began fluctuating at the end.</td></tr>
<tr><td>
</td><td>Maintained stable at the beginning at the value of 0 and began fluctuating at the end.</td></tr>
</table>

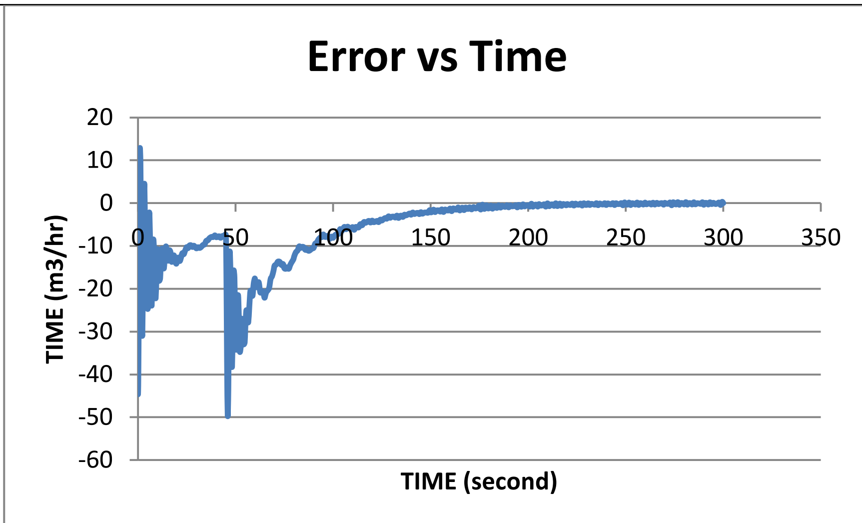
- Feedforward-feedback Control

<table>
<tr>
<td>
</td>
<td>Area of error =

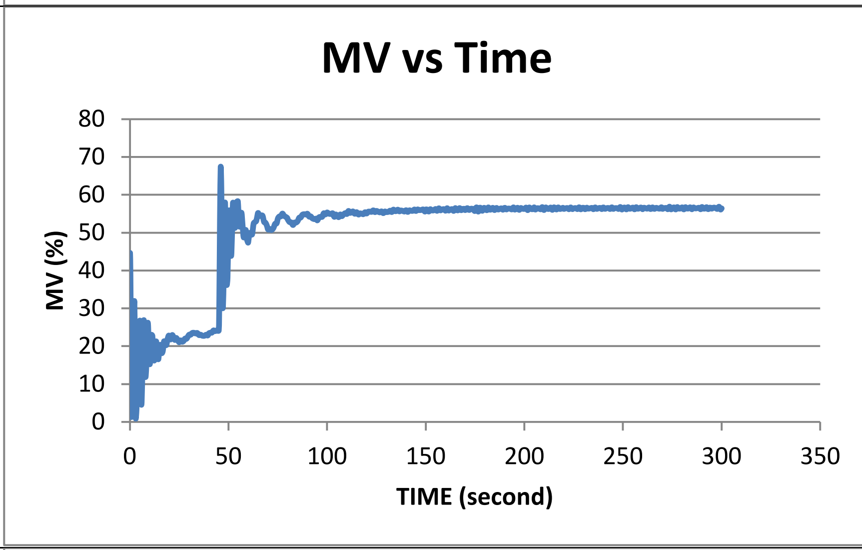
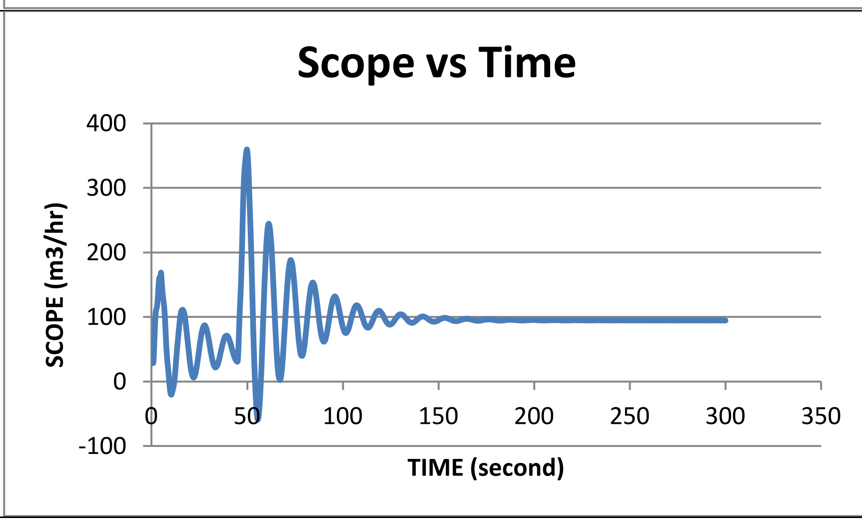
3.10E+14

Maintained stable at the beginning at the value of 0 and began fluctuating at the end.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the beginning at the value of 0 and began fluctuating at the end.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the beginning at the value of 0 and began fluctuating at the end.</td>
</tr>
</table>

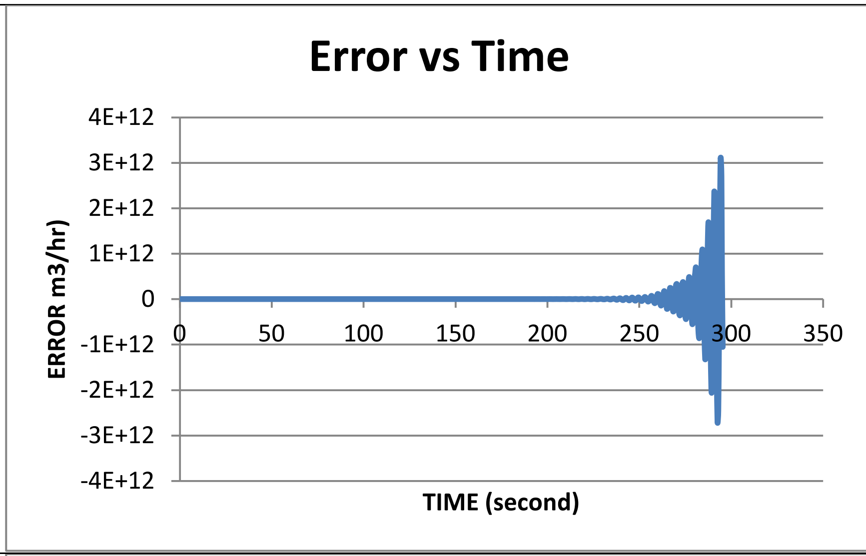
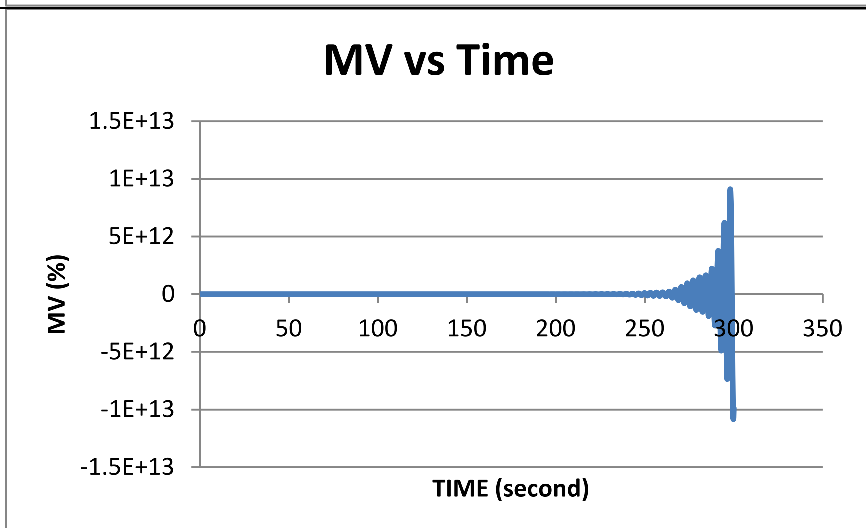
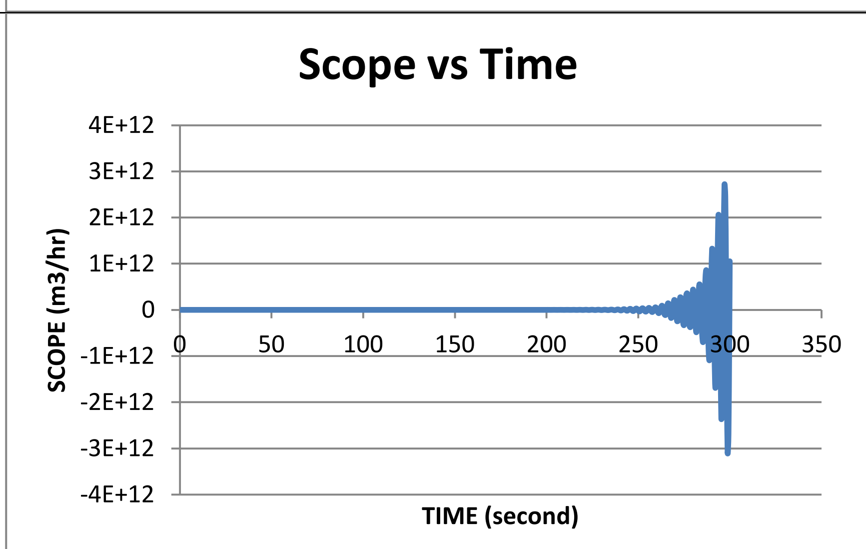
- IMC Control

<table>
<tr>
<td>
</td>
<td>Area of error =

1.71E+03

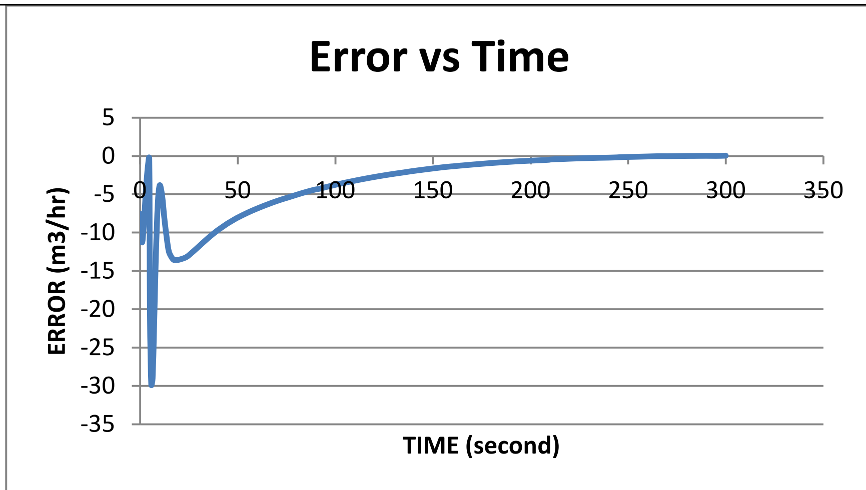
Fluctuating at the beginning and then maintained stable until the end of process.</td>
</tr>
<tr>
<td>
</td>
<td>Fluctuating at the beginning and then maintained stable until the end of process.</td>
</tr>
<tr>
<td>
</td>
<td>Fluctuating at the beginning and then maintained stable until the end of process.</td>
</tr>
</table>

- Smith Control

	Area of error = 1.74E+12 Maintained stable at the beginning at the value of 0 and began fluctuating at the end.
	Maintained stable at the beginning at the value of 0 and began fluctuating at the end.
	Maintained stable at the beginning at the value of 0 and began fluctuating at the end.

7.1.2 FLOW2

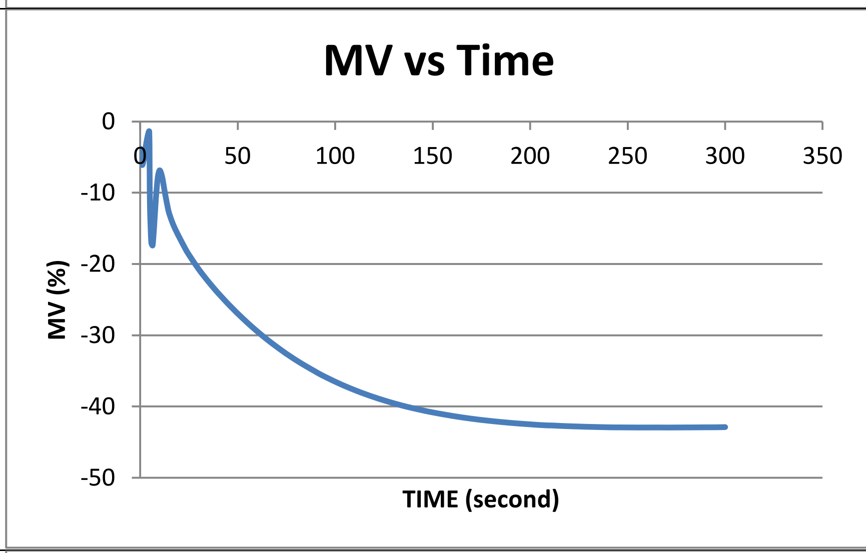
- Cascade Control



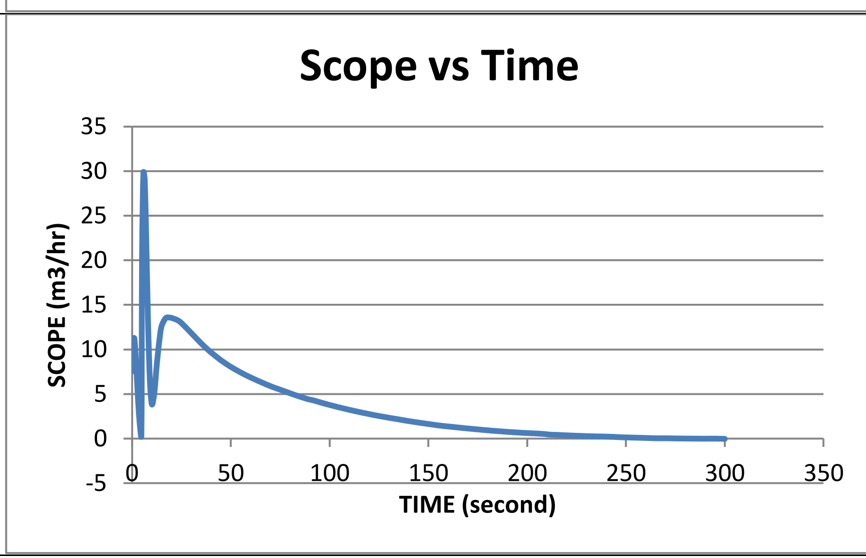
Area of error =

1.03E+03

Fluctuating at the beginning and maintained stable until the end process.

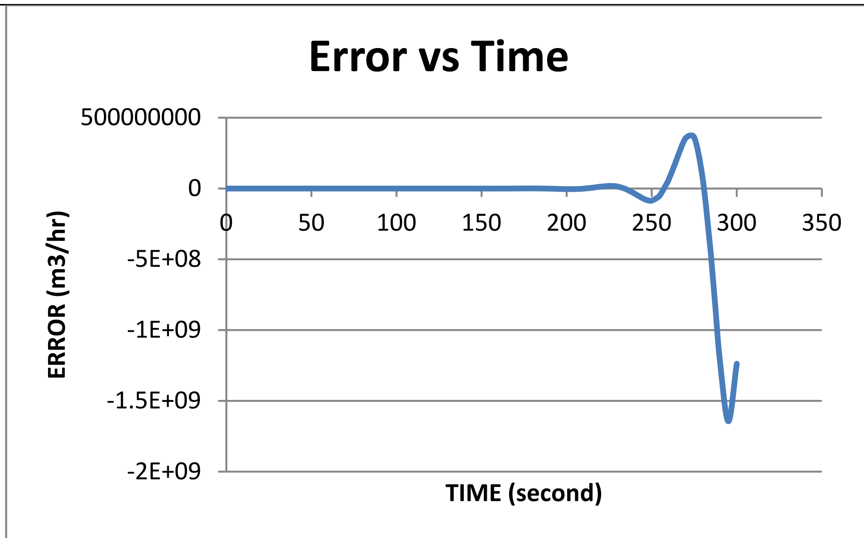


Fluctuating at the beginning and the value keep decreasing until negative value.



Fluctuating at the beginning and maintained stable until the end process.

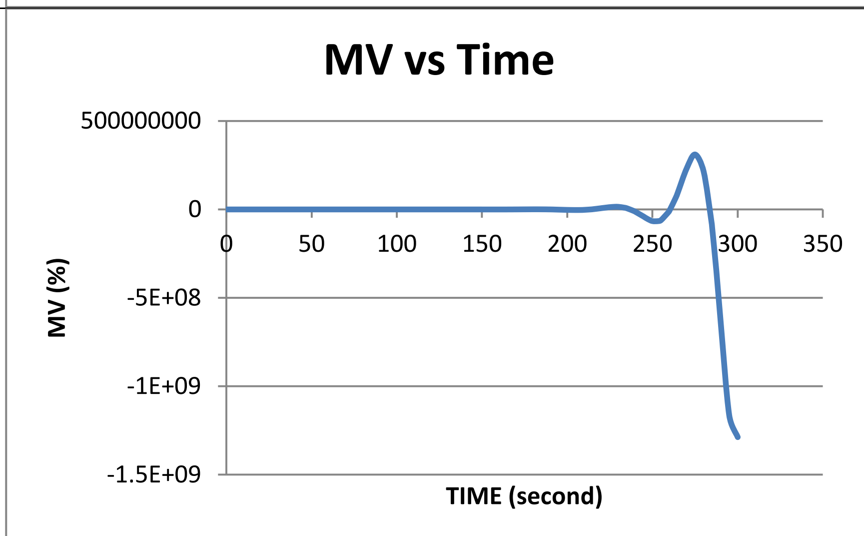
- Feedback Control



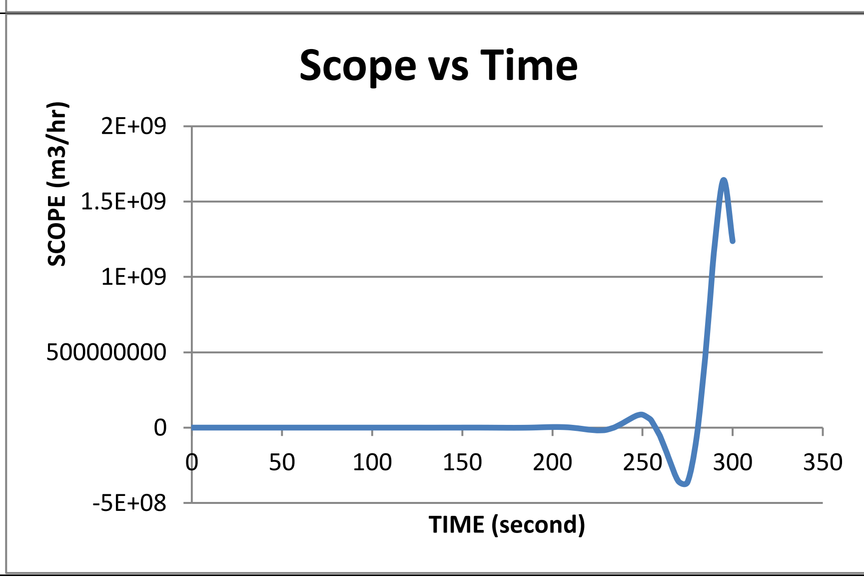
Area of error =

1.55E+10

Maintained stable at 0 value at the beginning of process and begin to fluctuate to negative value at the end.

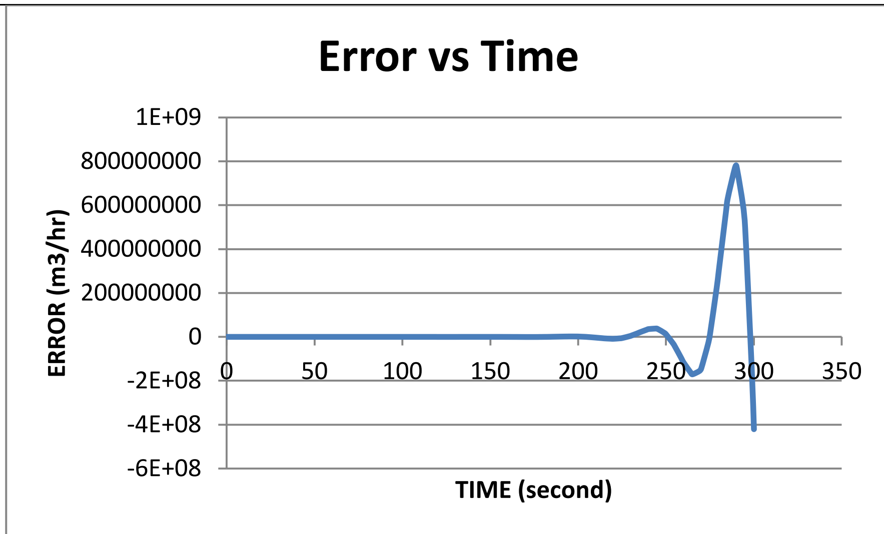
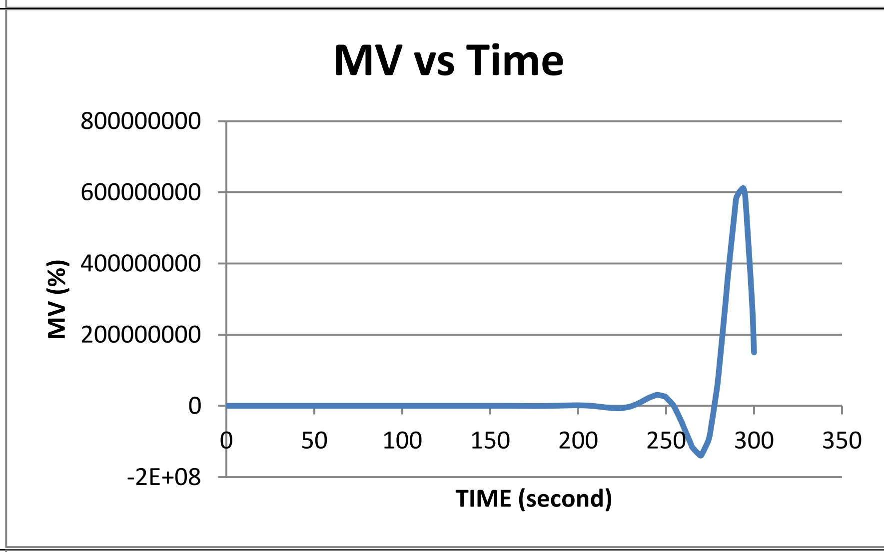
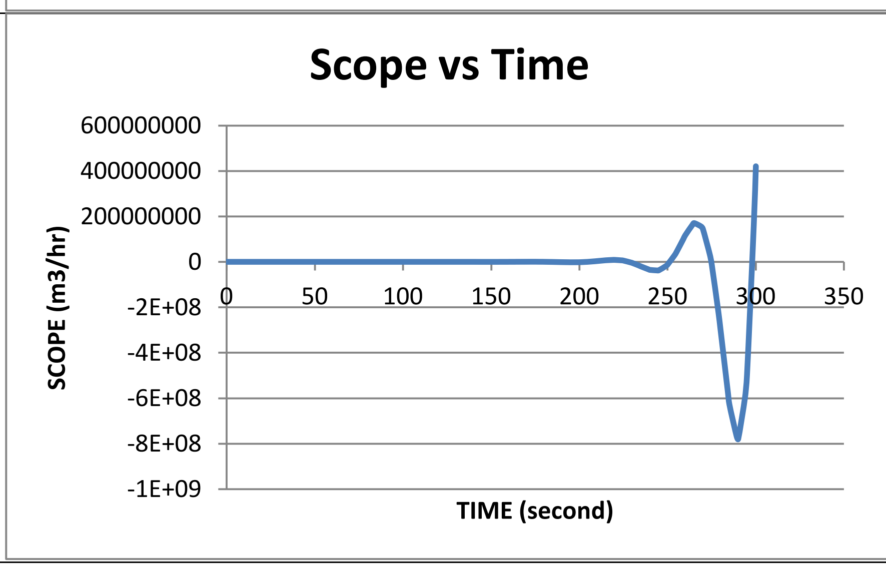


Maintained stable at 0 value at the beginning of process and begin to fluctuate to negative value at the end.

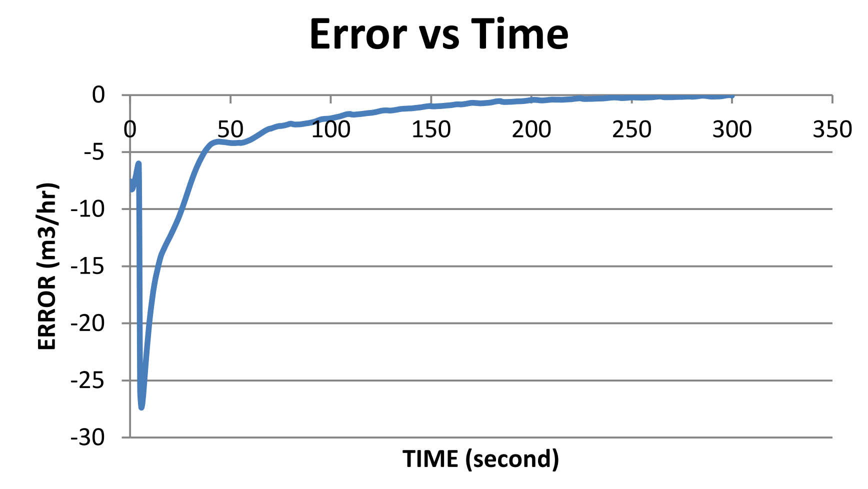


Maintained stable at 0 value at the beginning of process and begin to fluctuate to positive value at the end.

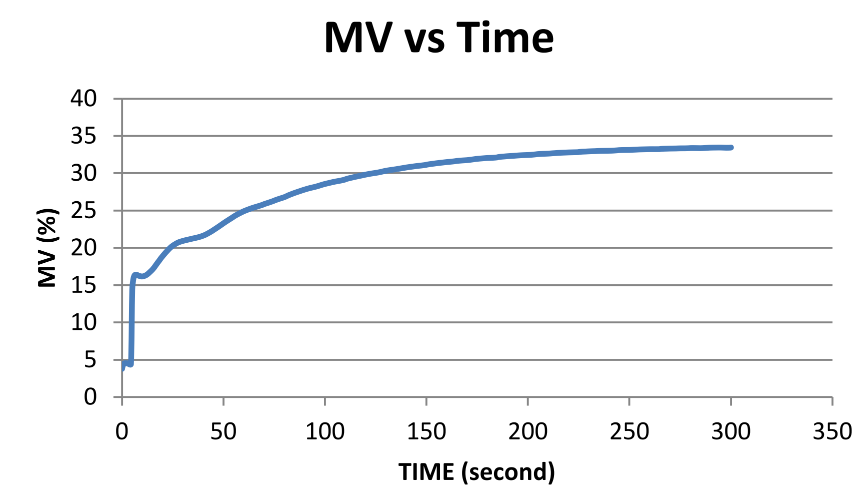
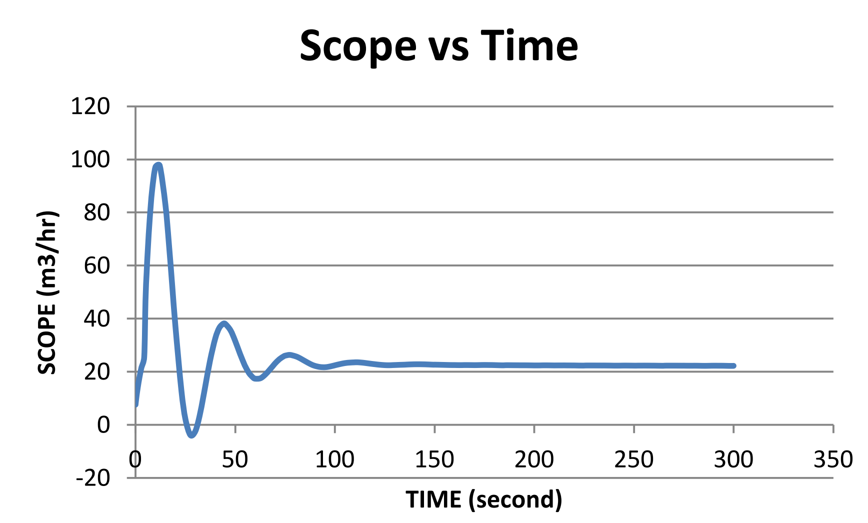
- Feedforward-feedback Control

	Area of error = 8.29E+09 Maintained stable at 0 value at the beginning of process and begin to fluctuate to positive value at the end.
	Maintained stable at 0 value at the beginning of process and begin to fluctuate to positive value at the end.
	Maintained stable at 0 value at the beginning of process and begin to fluctuate to negative value at the end.

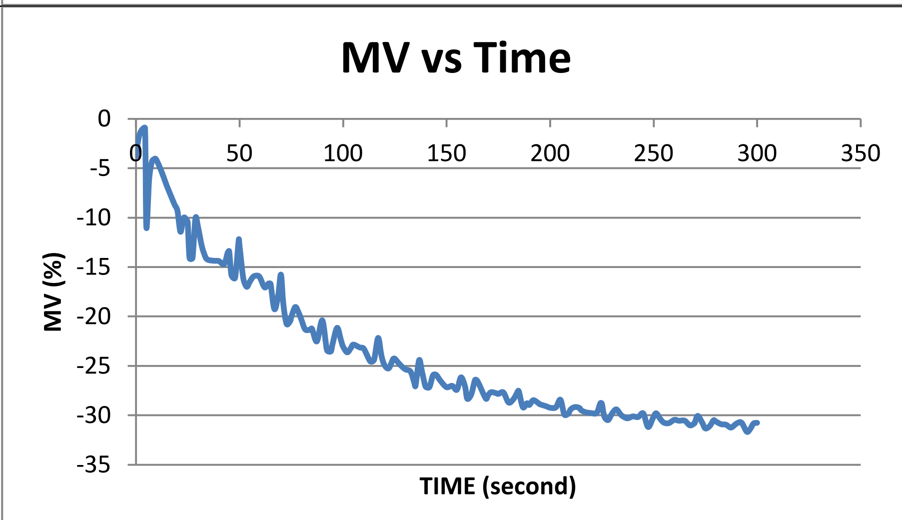
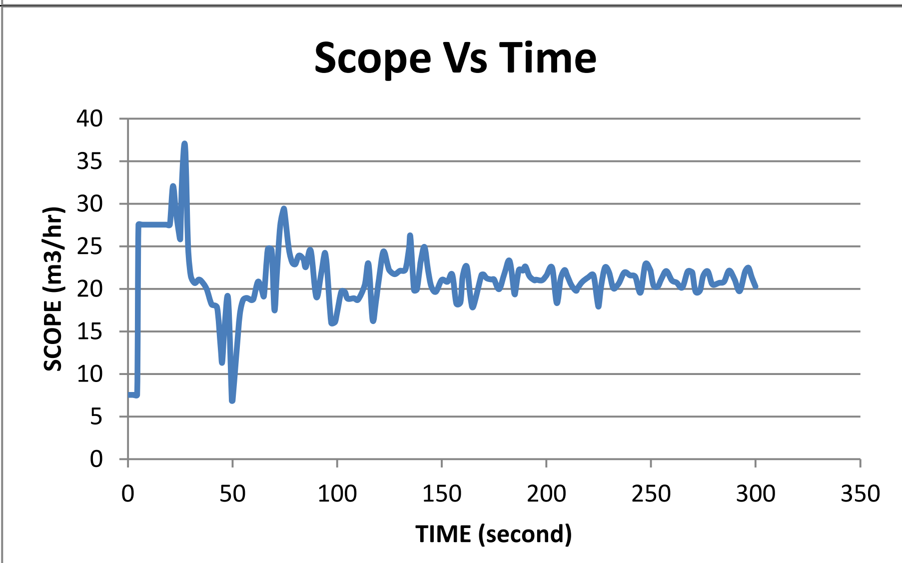
- IMC Control

<table>
<tr>
<td>
</td>
<td>Area of error =

97.865

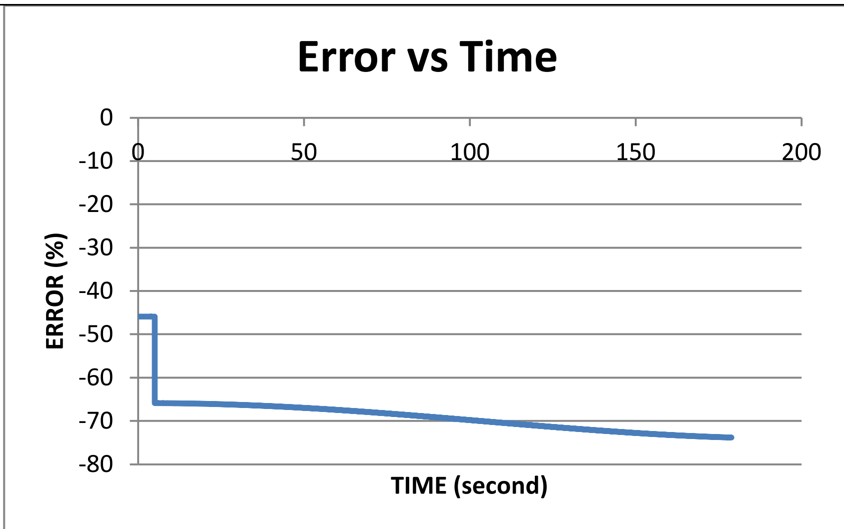
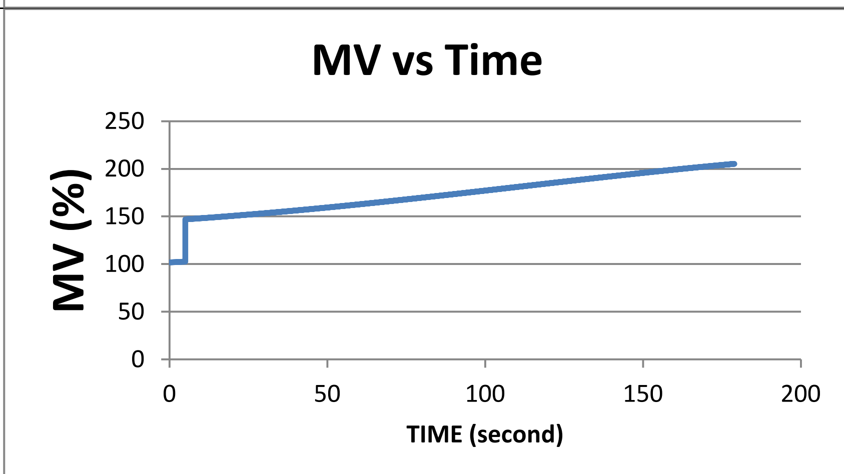
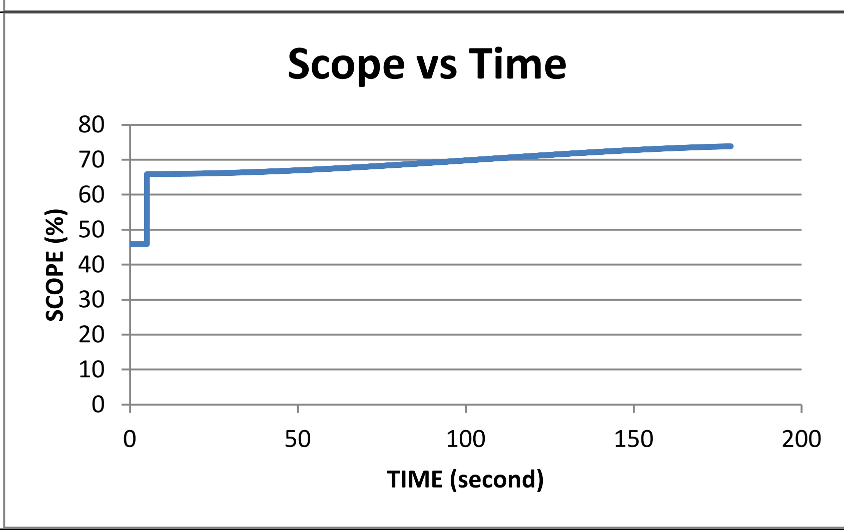
Fluctuating at the beginning and maintained stable until the end process</td>
</tr>
<tr>
<td>
</td>
<td>Fluctuating at the beginning and maintained stable until the end process</td>
</tr>
<tr>
<td>
</td>
<td>Fluctuating at the beginning and maintained stable until the end process</td>
</tr>
</table>

- Smith Control

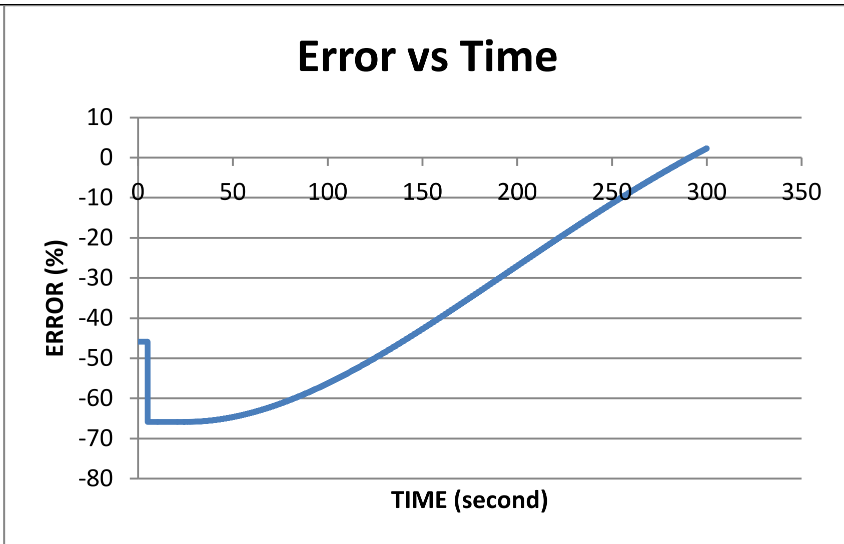
	Area of error = 6.37E+03 Fluctuating and unstable
	Fluctuating and unstable
	Fluctuating and unstable

7.1.3 LEVEL1

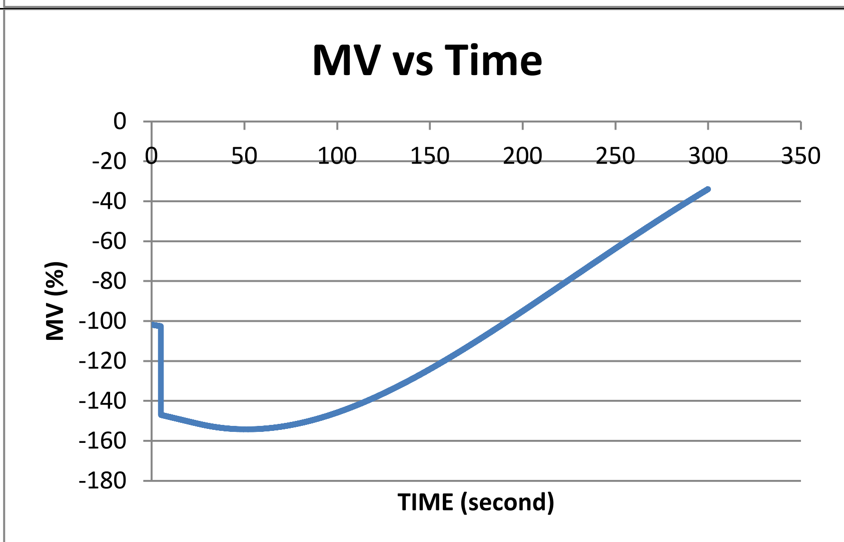
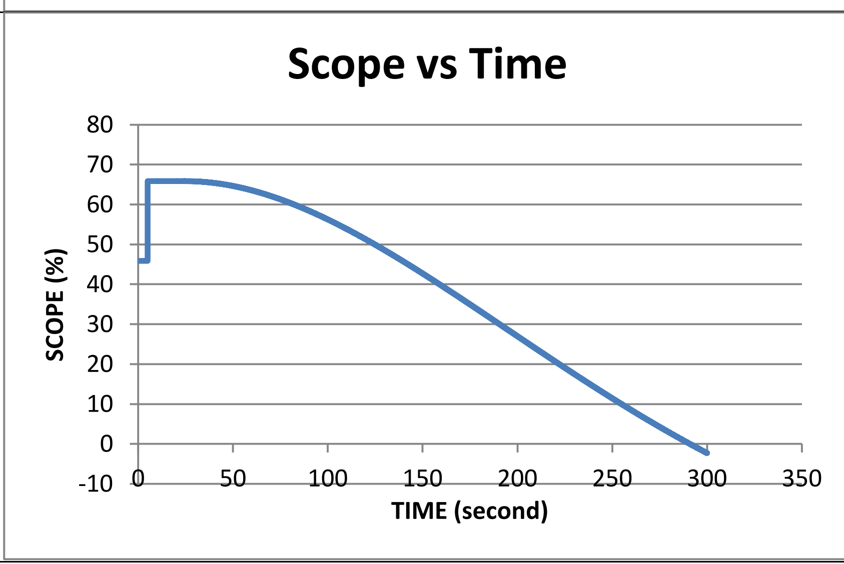
- Cascade Control

	Area of error = 2.10E+04 Unstable
	Stable
	Stable

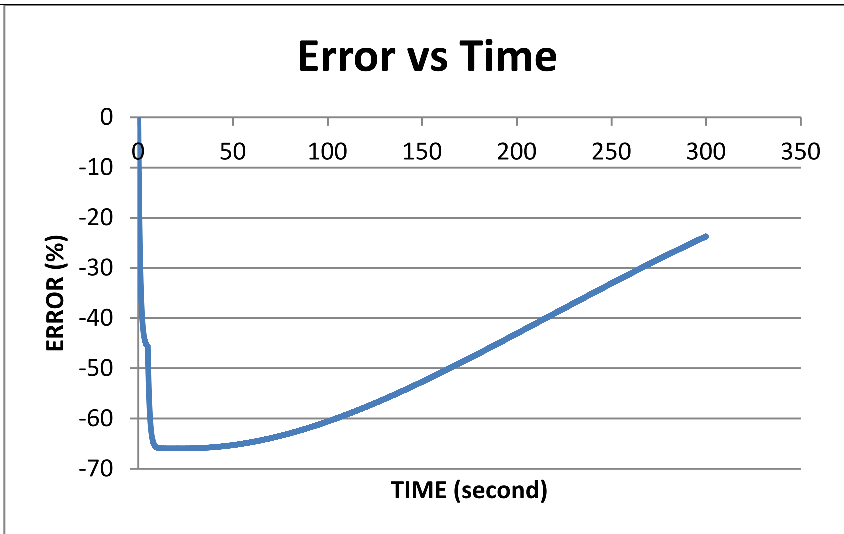
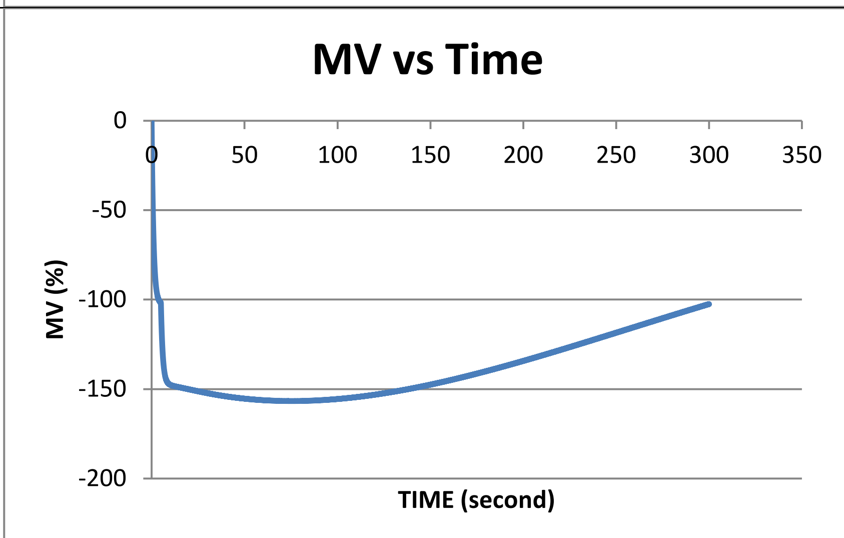
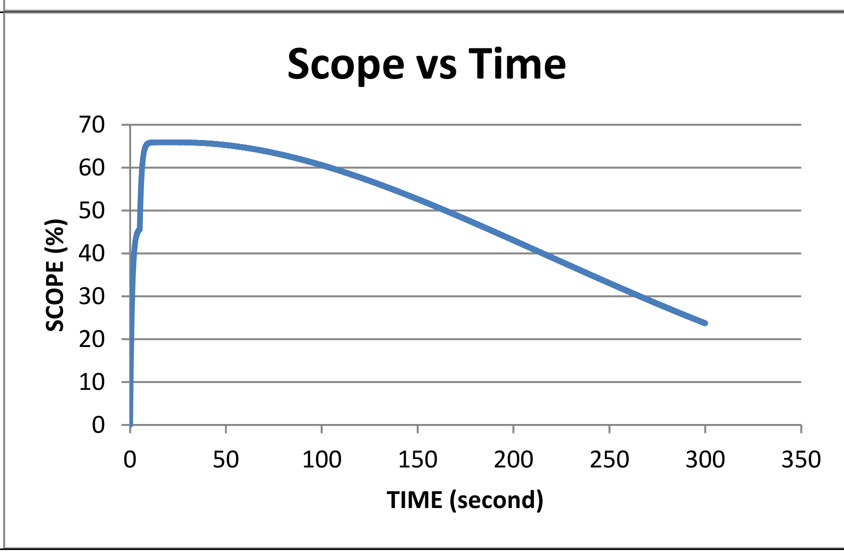
- Feedback Control

<table>
<tr>
<td>
</td>
<td>Area of error =

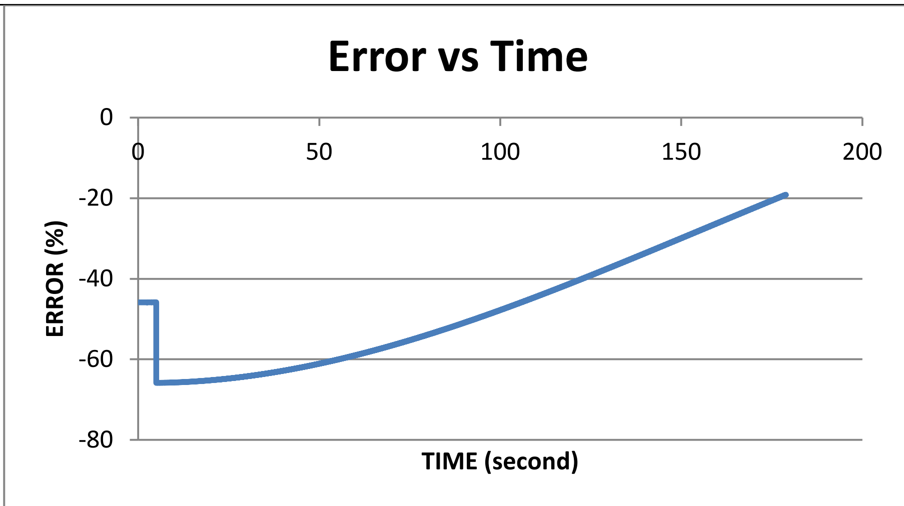
1.16E+04

Unstable and has negative value.</td>
</tr>
<tr>
<td>
</td>
<td>Unstable and has negative value.</td>
</tr>
<tr>
<td>
</td>
<td>Stable at the beginning and then begin decreased constantly.</td>
</tr>
</table>

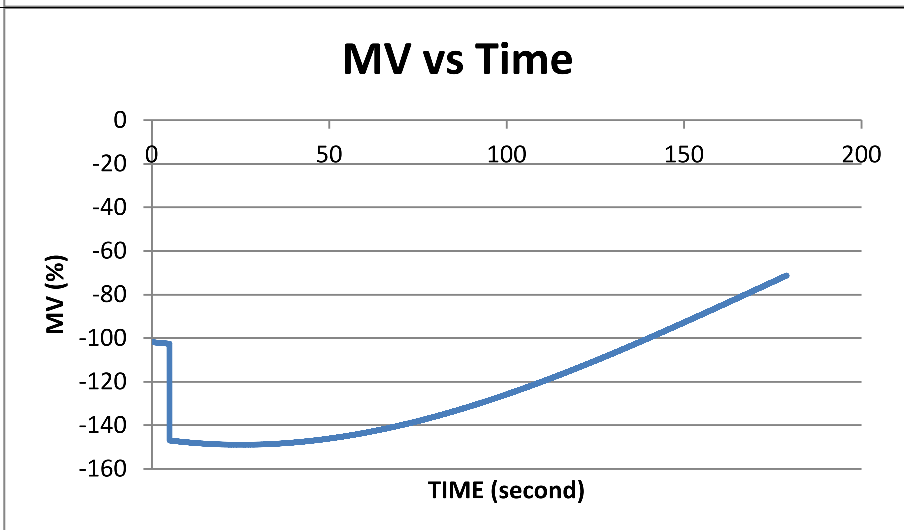
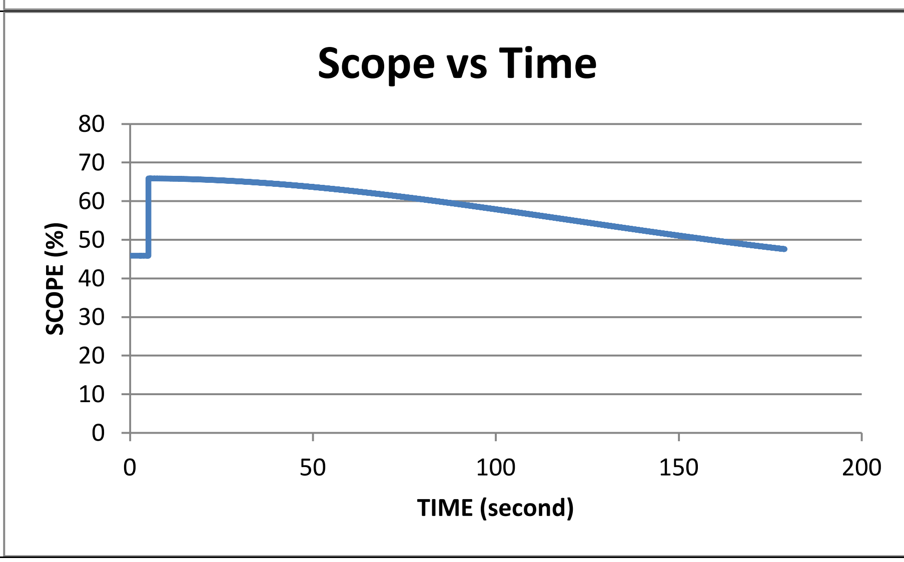
- Feedforward-feedback

	Area of error = 1.48E+04 Unstable and has negative value.
	Unstable and has negative value.
	Stable at the beginning and then begin decreased constantly.

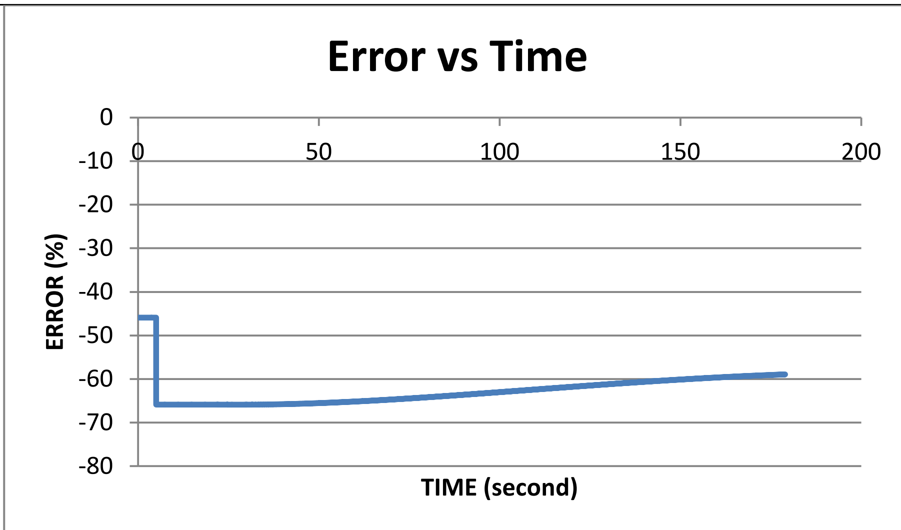
- IMC Control

<table>
<tr>
<td>
</td>
<td>Area of error =

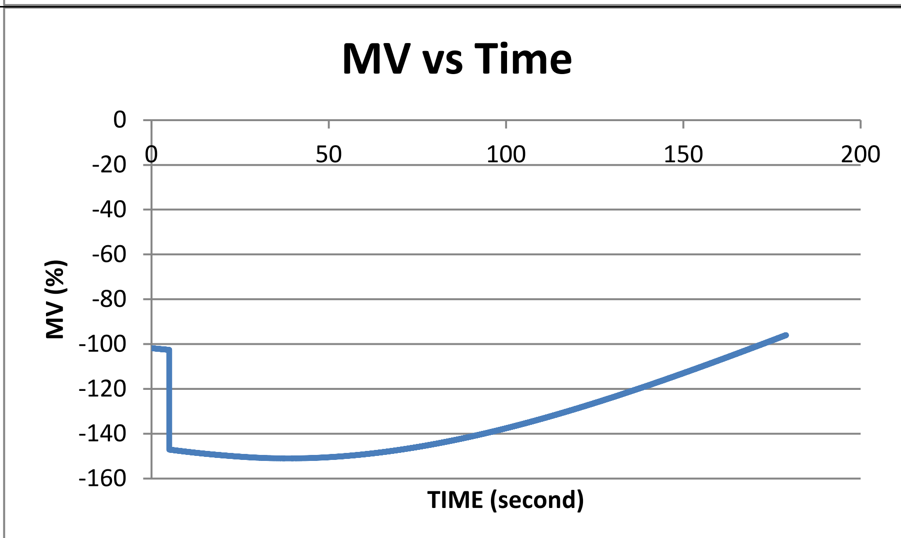
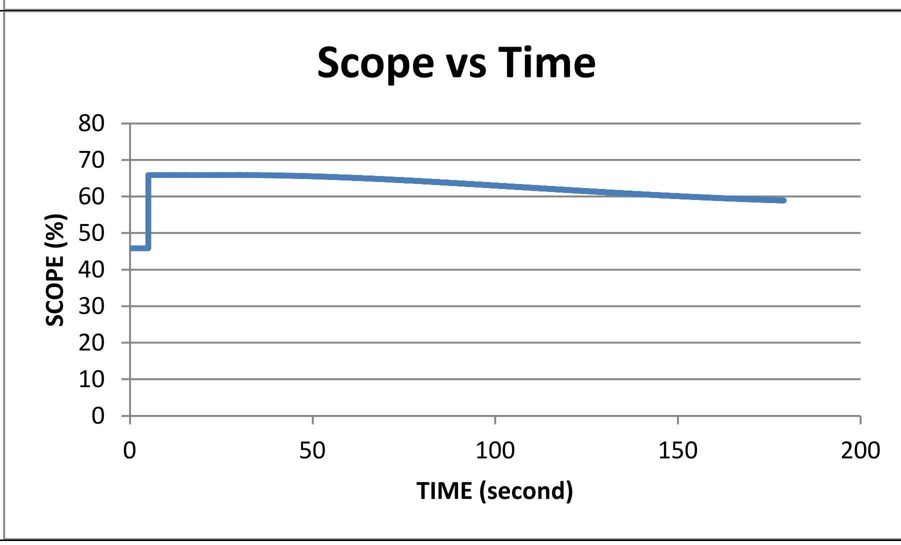
8.53E+03

Unstable and has negative value.</td>
</tr>
<tr>
<td>
</td>
<td>Unstable and has negative value.</td>
</tr>
<tr>
<td>
</td>
<td>Stable</td>
</tr>
</table>

- Smith Control

<table>
<tr>
<td>
</td>
<td>Area of error =

1.84E+04

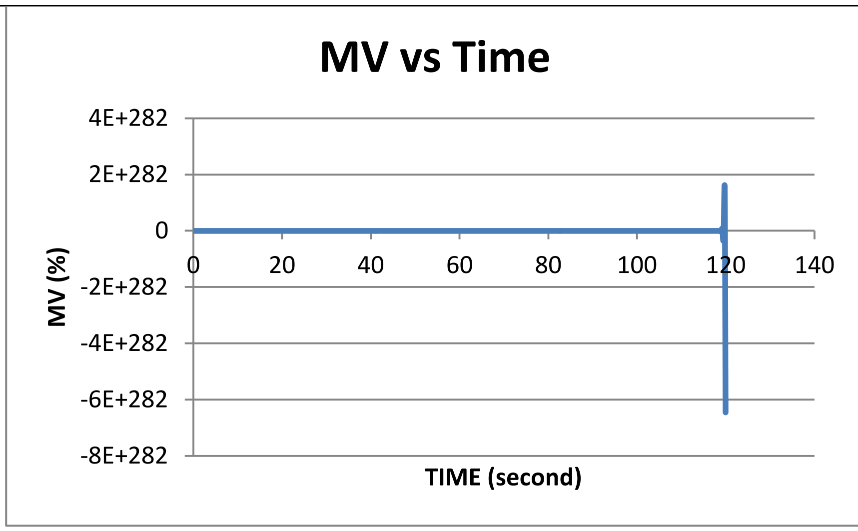
Unstable and has negative value</td>
</tr>
<tr>
<td>
</td>
<td>Unstable and has negative value</td>
</tr>
<tr>
<td>
</td>
<td>Stable</td>
</tr>
</table>

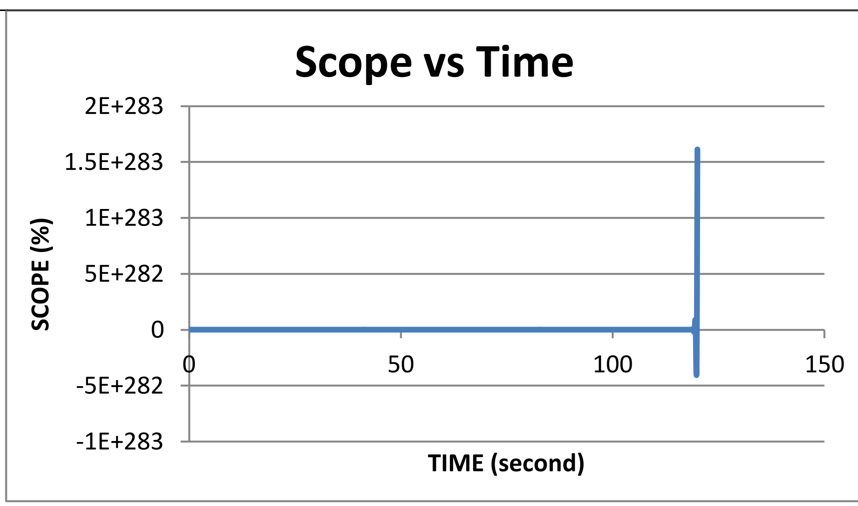
7.1.4 LEVEL2

- Cascade

<table>
<tr>
<td>


</td>
<td>
Area of error = 1.93E+285

Stable at the beginning and begin to fluctuate to negative value at the end.
</td>
</tr>
<tr>
<td>


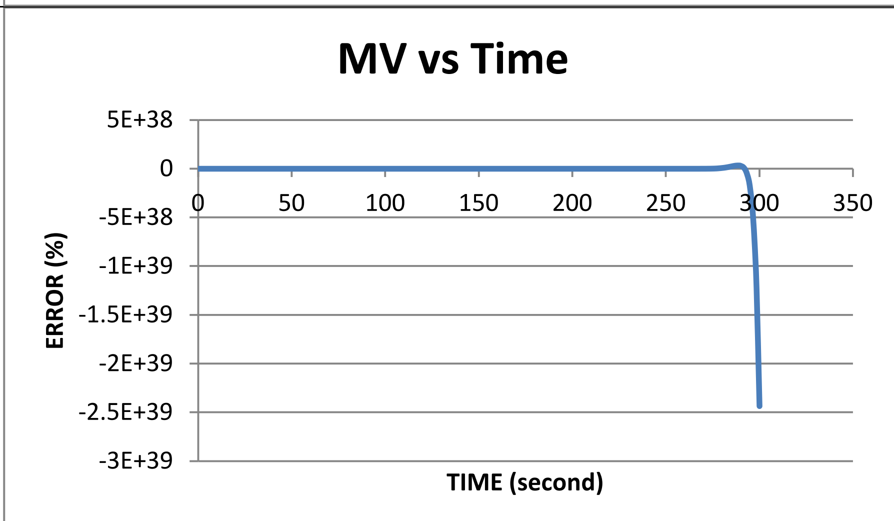
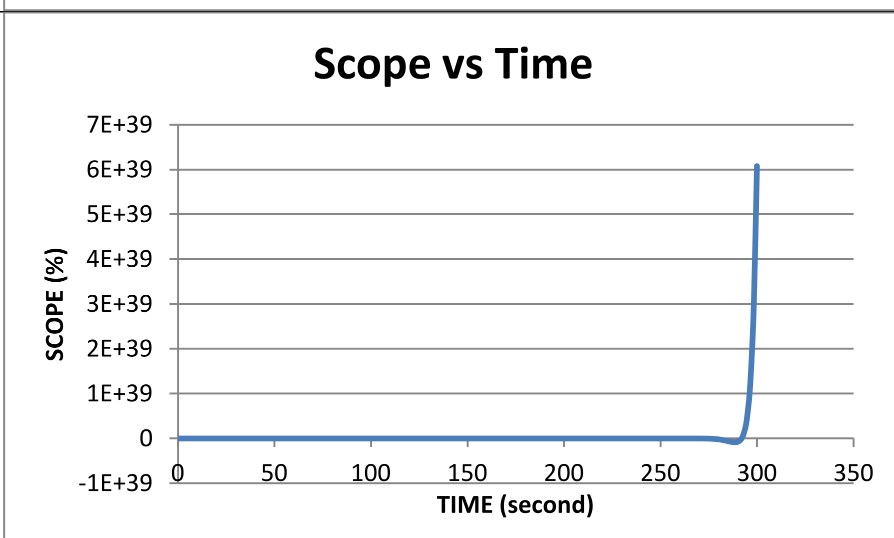
</td>
<td>
Stable at the beginning and begin to fluctuate to negative value at the end.
</td>
</tr>
<tr>
<td>


</td>
<td>
Stable at the beginning and begin to fluctuate to negative value at the end.
</td>
</tr>
</table>

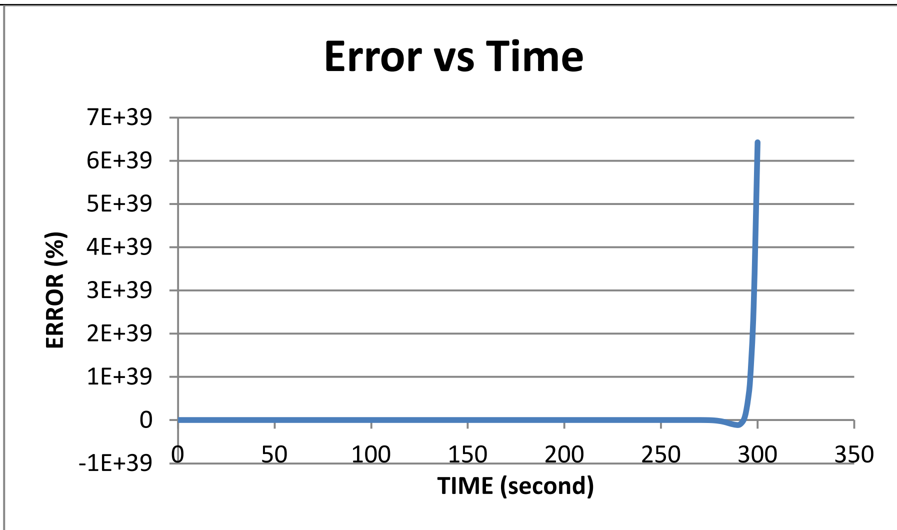
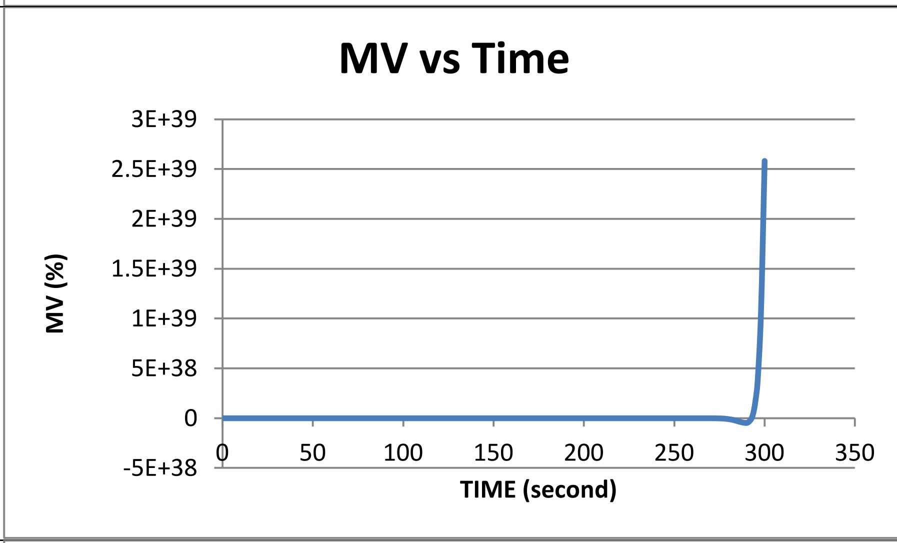
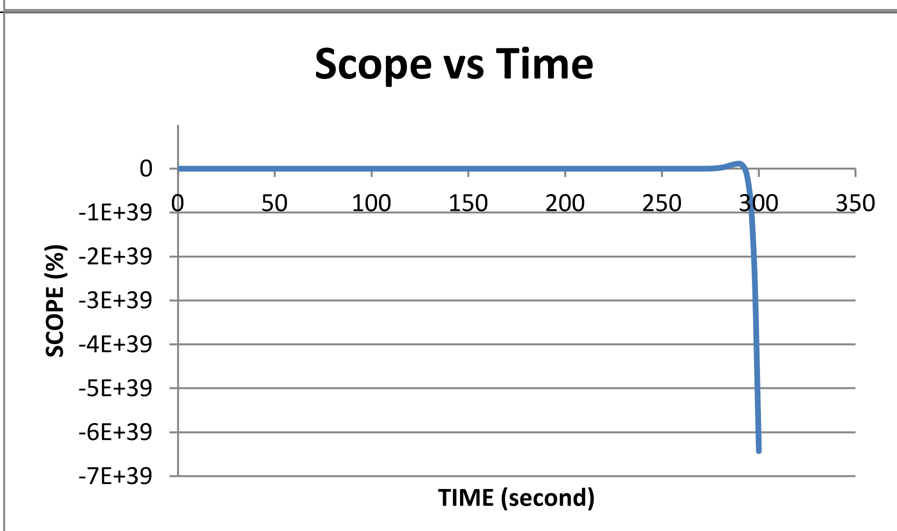
- Feedback Control

<table>
<tr>
<td>
</td>
<td>Area of error
=

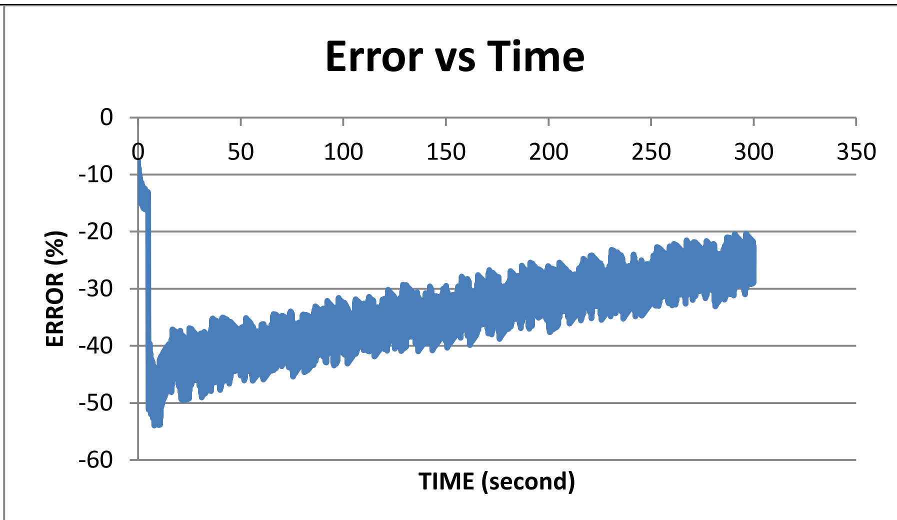
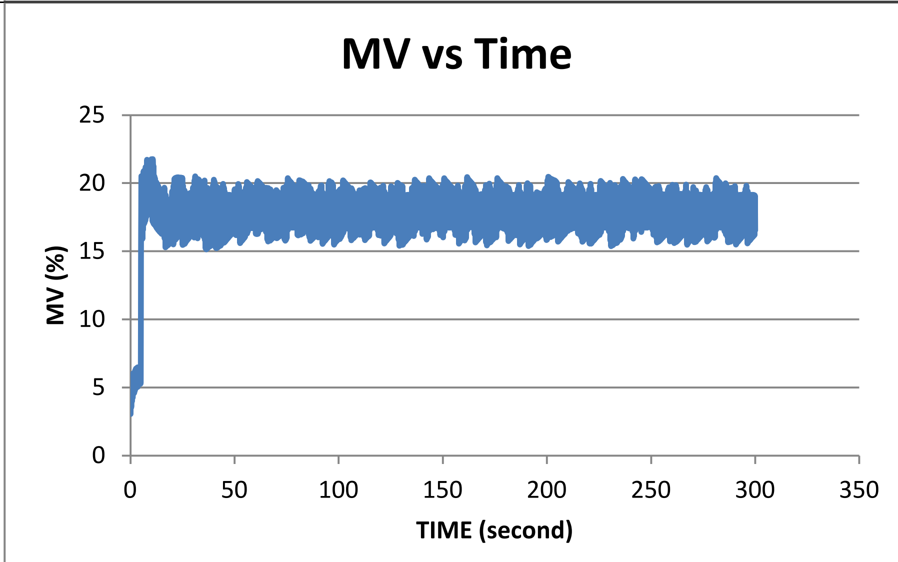
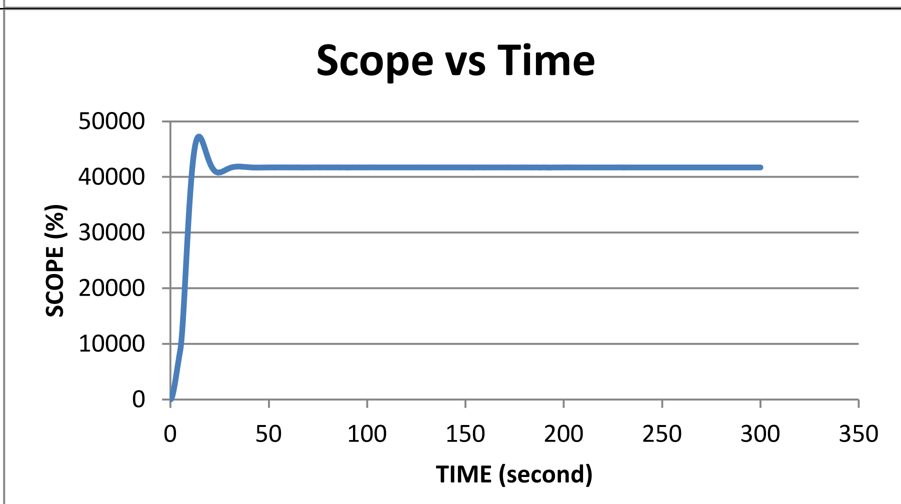
1.23E+40

Stable at the beginning and begin to fluctuate to negative value at the end</td>
</tr>
<tr>
<td>
</td>
<td>Stable at the beginning and begin to fluctuate to negative value at the end</td>
</tr>
<tr>
<td>
</td>
<td>Stable at the beginning and begin to fluctuate to positive value in short time</td>
</tr>
</table>

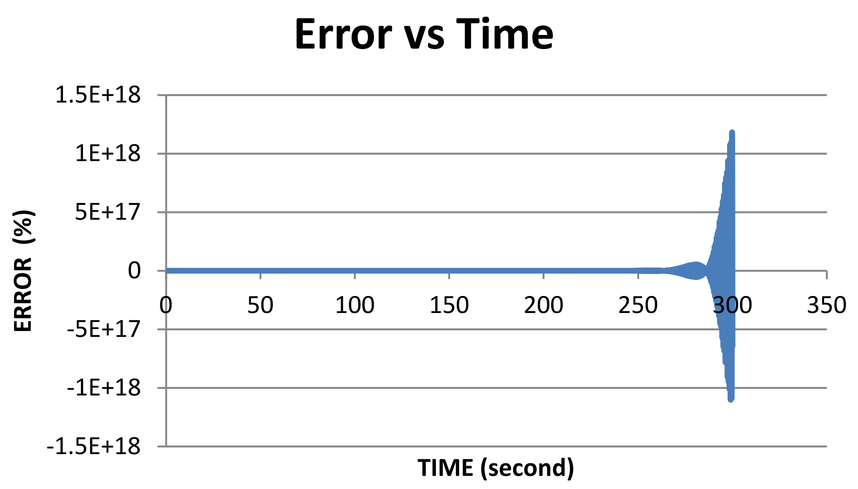
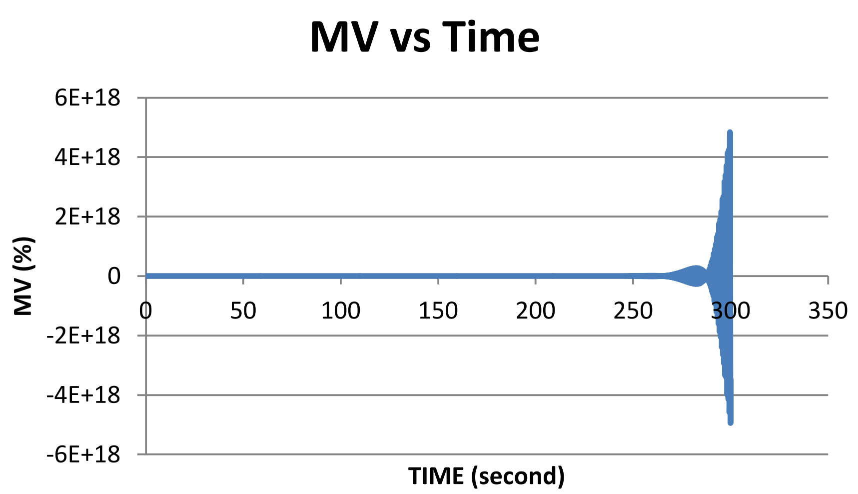
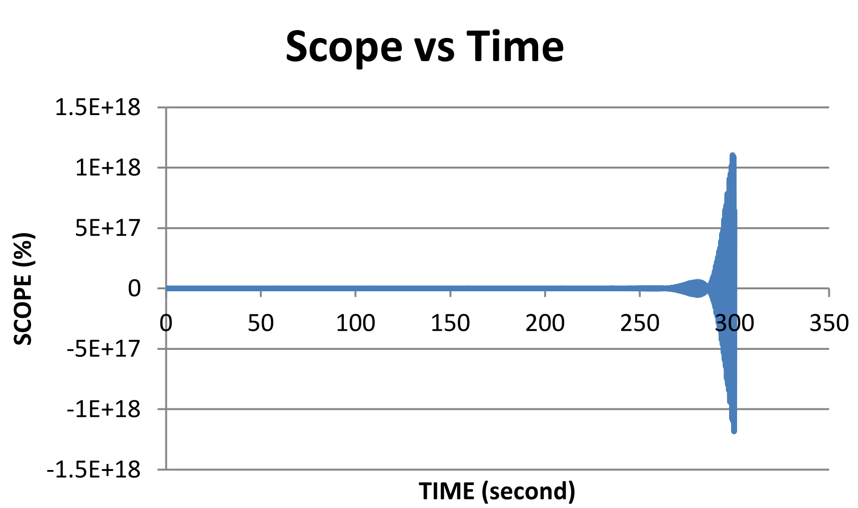
- Feedforward-feedback Control

	Area of error = 1.27E+40 Stable at the beginning and begin to fluctuate to positive value in short time
	Stable at the beginning and begin to fluctuate to positive value in short time
	Stable at the beginning and begin to fluctuate to negative value in short time

- IMC Control

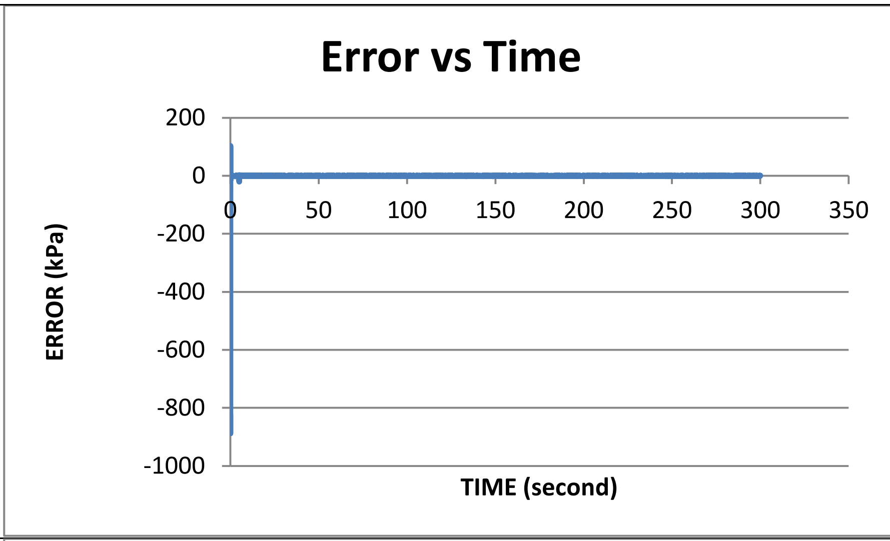
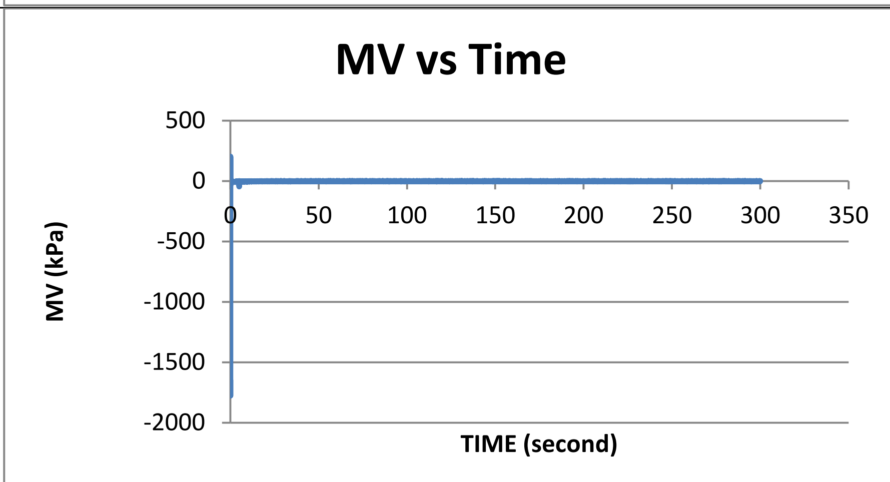
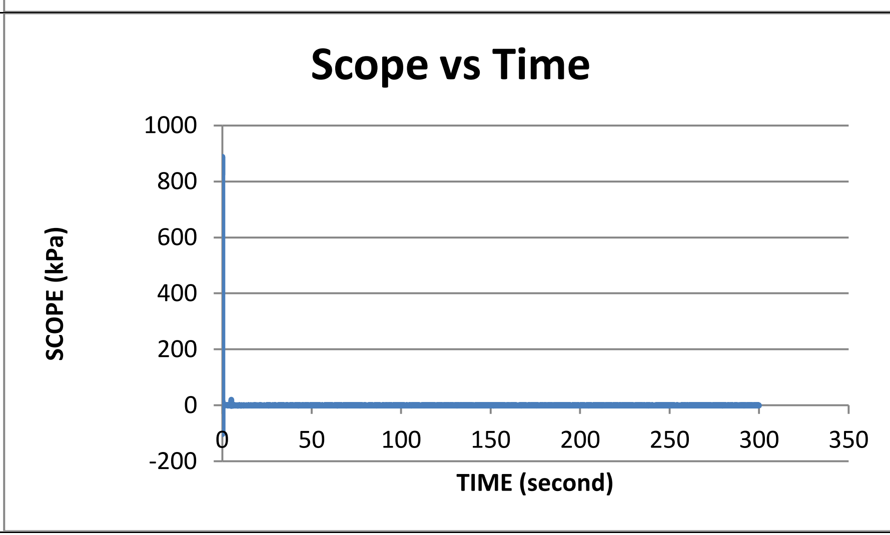
	Area of error = -1.03E+04 Fluctuated and has negative value
	Fluctuated and stable
	Fluctuated at the beginning and begin stable until the end of process

- Smith Control

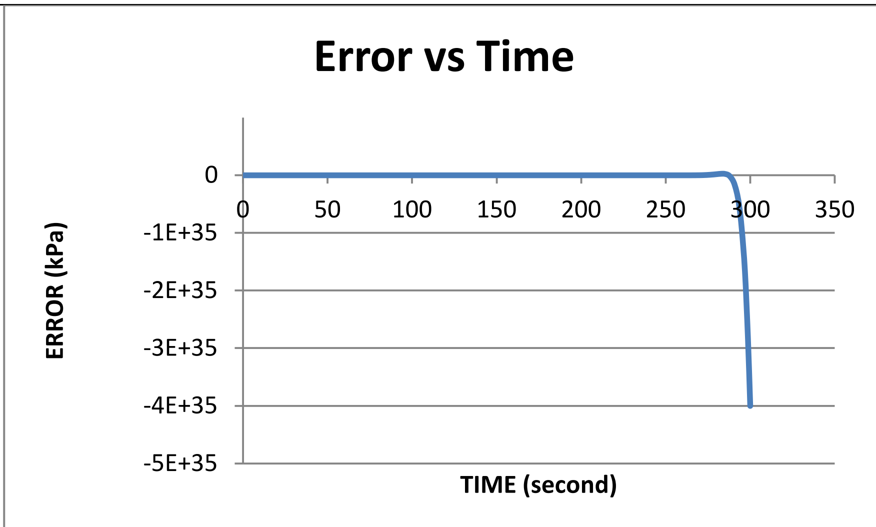
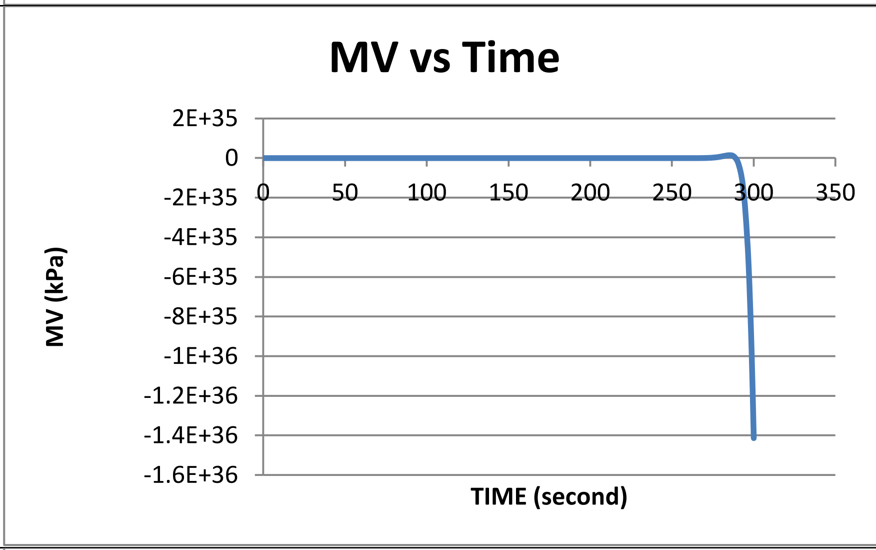
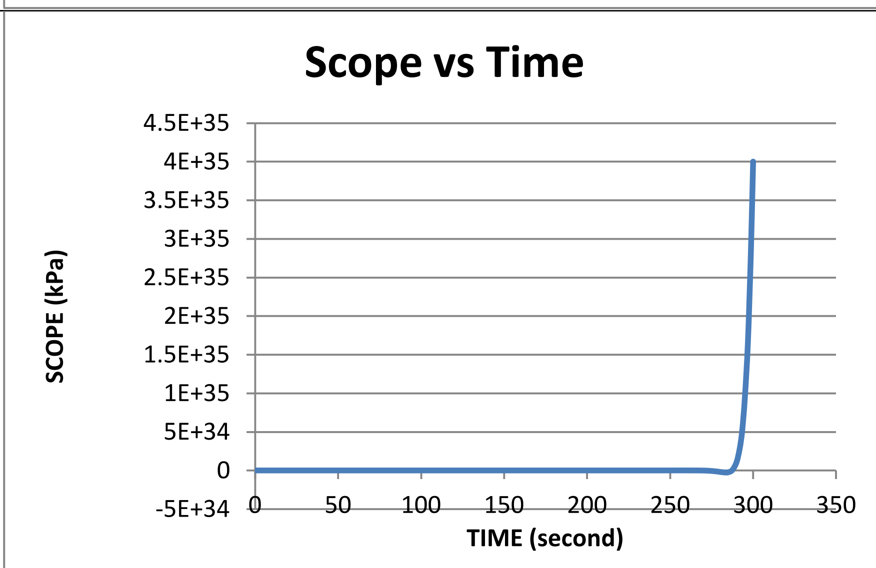
	Area of error = 8.02E+16 Fluctuated and unstable
	Fluctuated and unstable
	Fluctuated and unstable

7.1.5 PRESSURE1

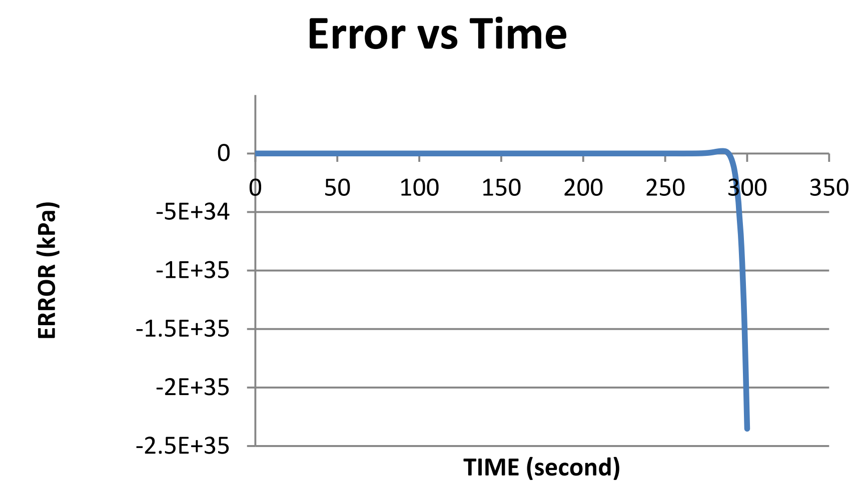
- Cascade

	Area of error = 1.354 Unstable as the value stayed only at zero
	Unstable as the value stayed only at zero
	Unstable as the value stayed only at zero

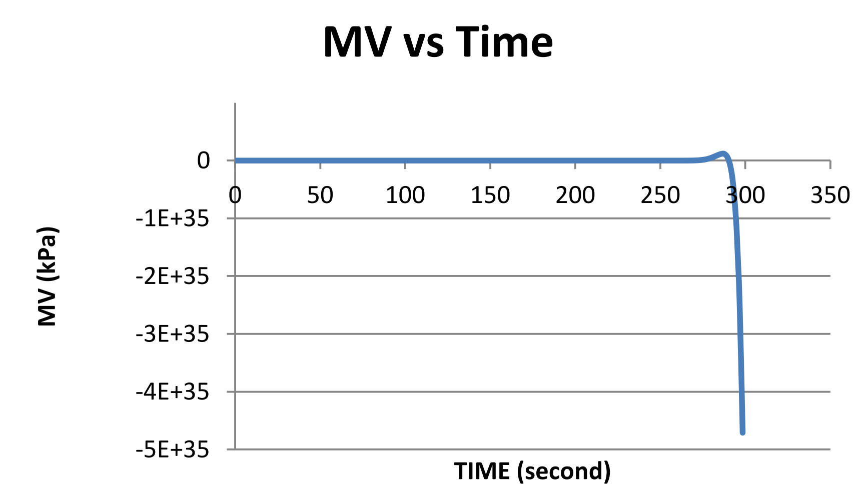
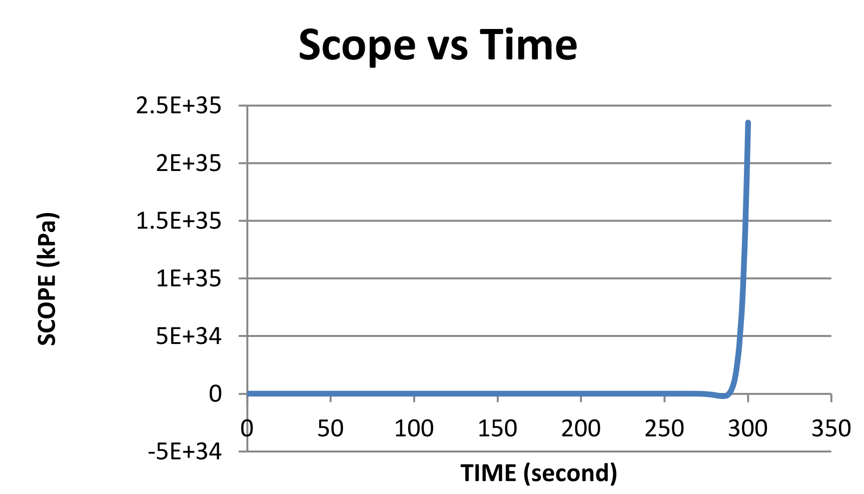
- Feedback Control

	Area of error = 1.31E+36 Stable at beginning at value of 0 and begin to decrease at negative value in short time
	Stable at beginning at value of 0 and begin to decrease at negative value in short time
	Stable at beginning at value of 0 and begin to increase at positive value in short time

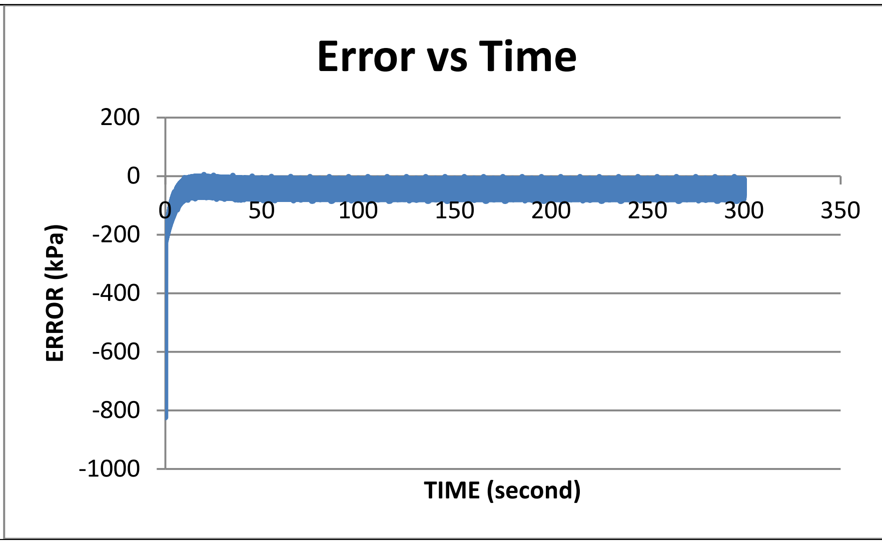
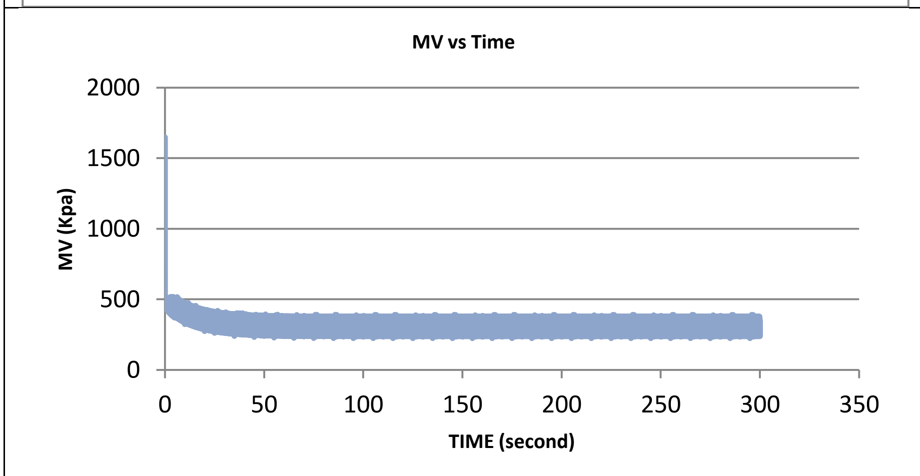
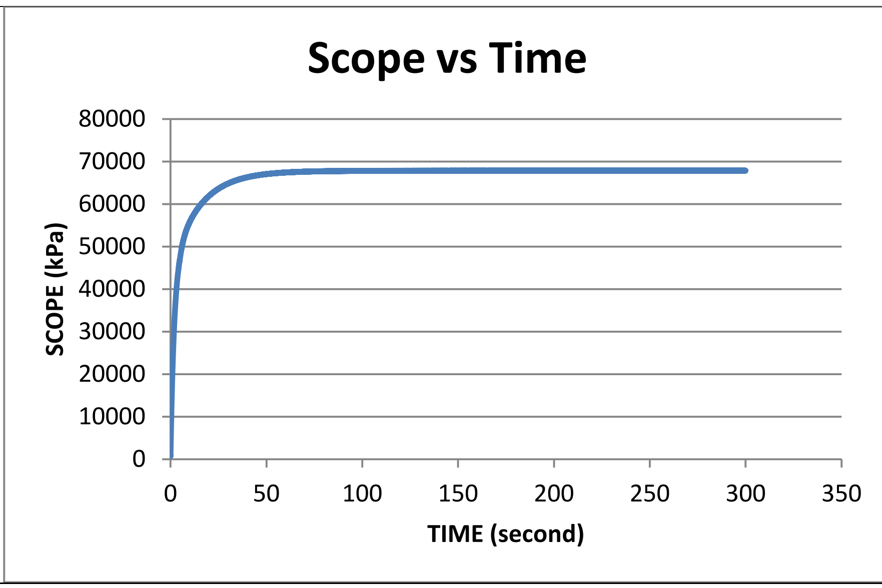
- Feedforward-feedback Control

<table>
<tr>
<td>
</td>
<td>Area of error =

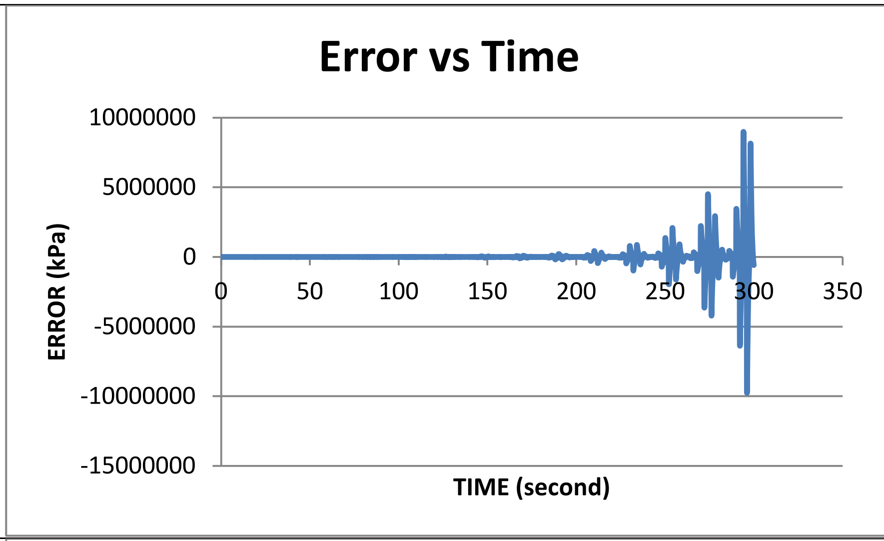
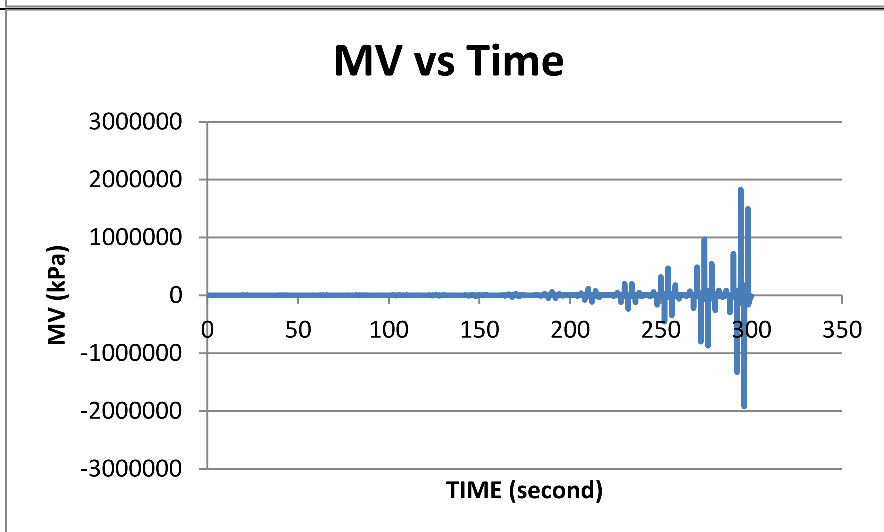
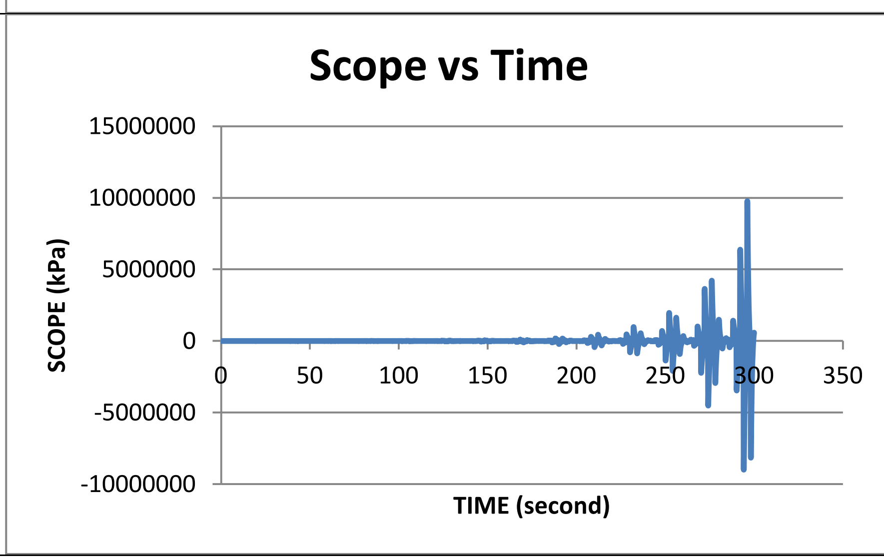
6.99E+35

Stable at beginning at value of 0 and begin to decrease at negative value in short time</td>
</tr>
<tr>
<td>
</td>
<td>Stable at beginning at value of 0 and begin to decrease at negative value in short time</td>
</tr>
<tr>
<td>
</td>
<td>Stable at beginning at value of 0 and begin to increase at positive value in short time</td>
</tr>
</table>

- IMC Control

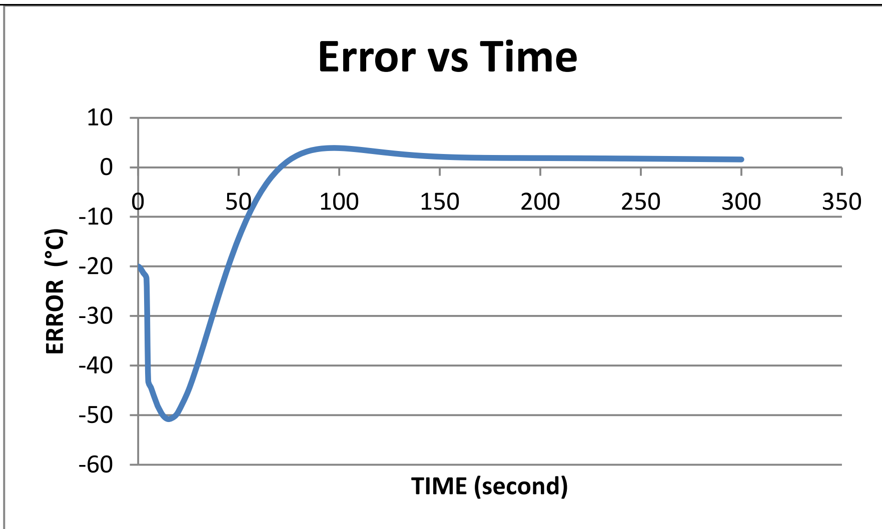
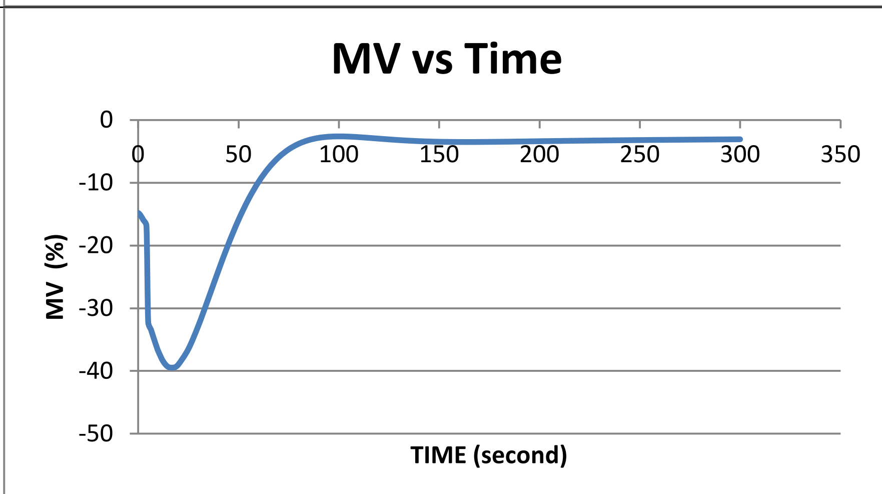
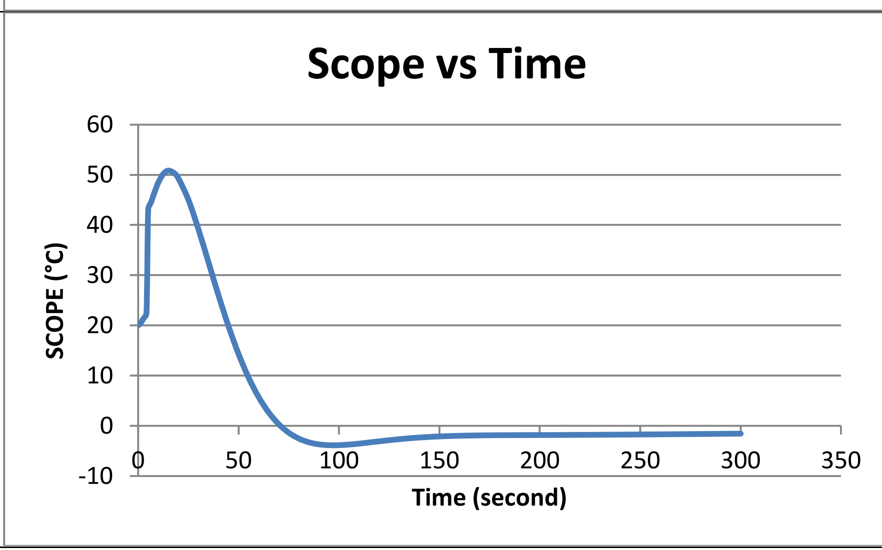
	Area of error: 10241.79 Fluctuated at negative value
	Fluctuated at positive value
	Stable but at a very high value

- Smith Control

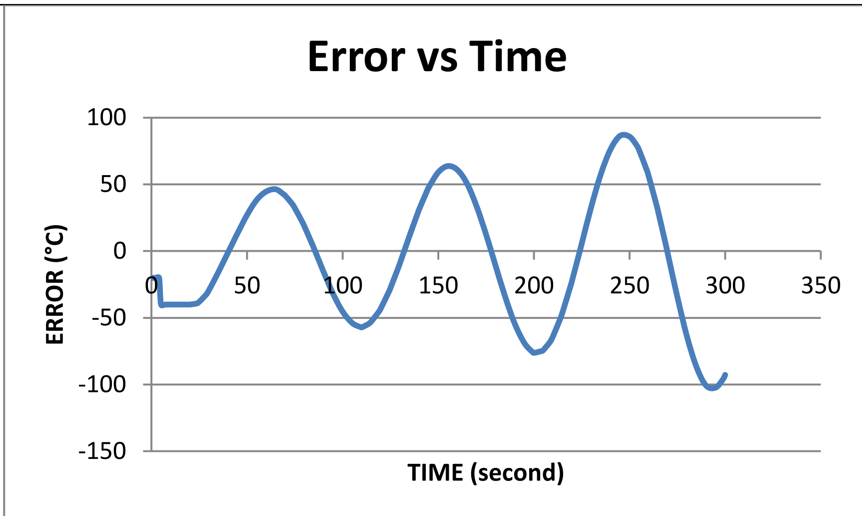
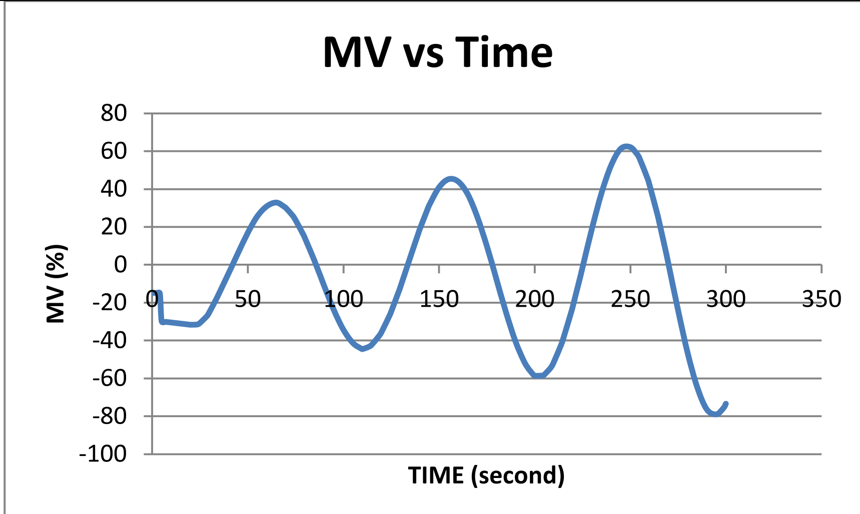
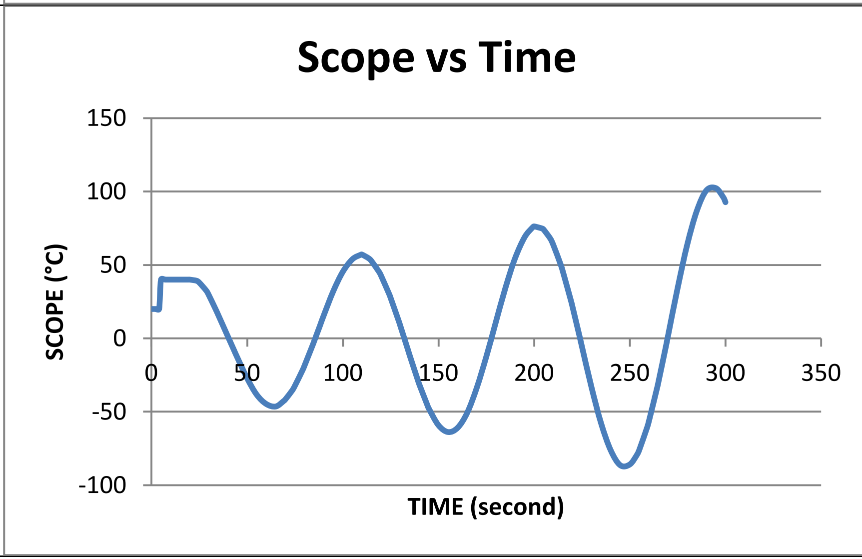
	Area of error = 1.24E+06 Stable but fluctuated at a very high value
	Stable but fluctuated at a very high value
	Stable but fluctuated at a very high value

7.1.6 TEMPERATURE5

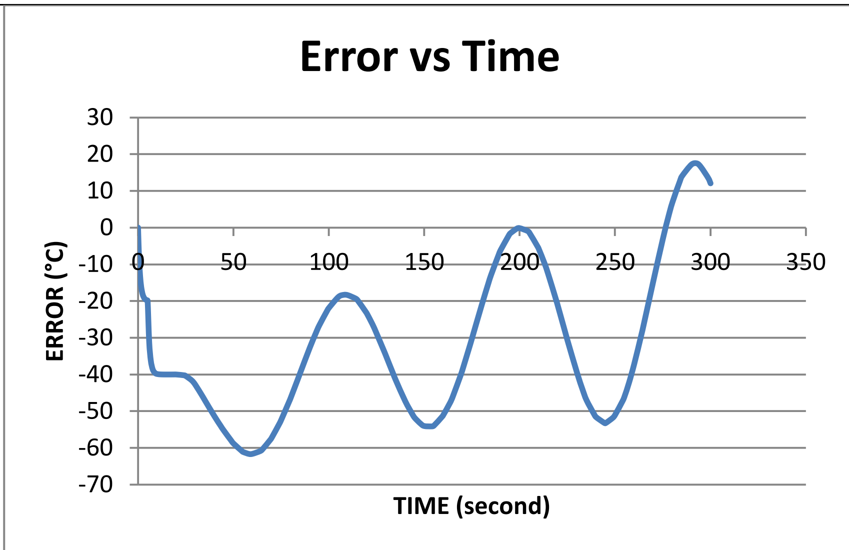
- Cascade Control

	Area of error: 1441.73 Fluctuated to negative value at the beginning and began to stable until the end
	Fluctuated to negative value at the beginning and began to stable until the end
	Fluctuated at the beginning and begin to decrease to negative value until the end

- Feedback Control

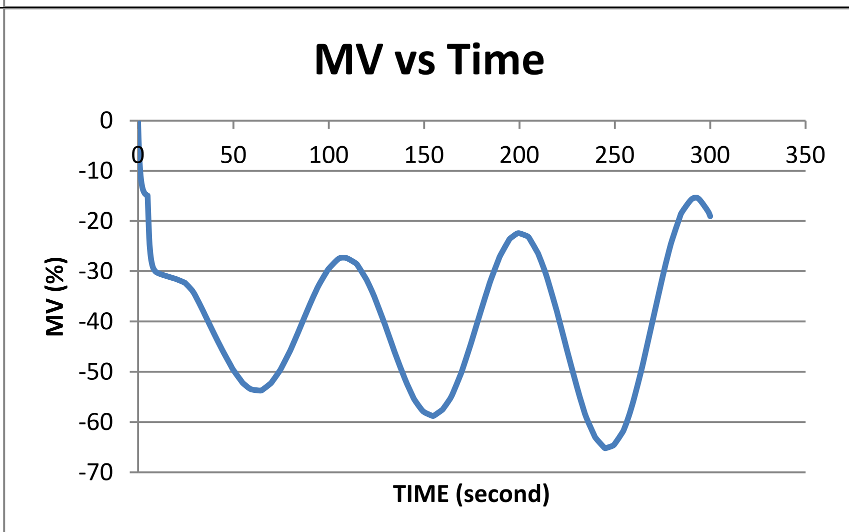
	Area of error: 1633.74 Fluctuated to negative value and unstable
	Fluctuated to negative value and unstable
	Fluctuated to negative value and unstable

- Feedforward-feedback Control

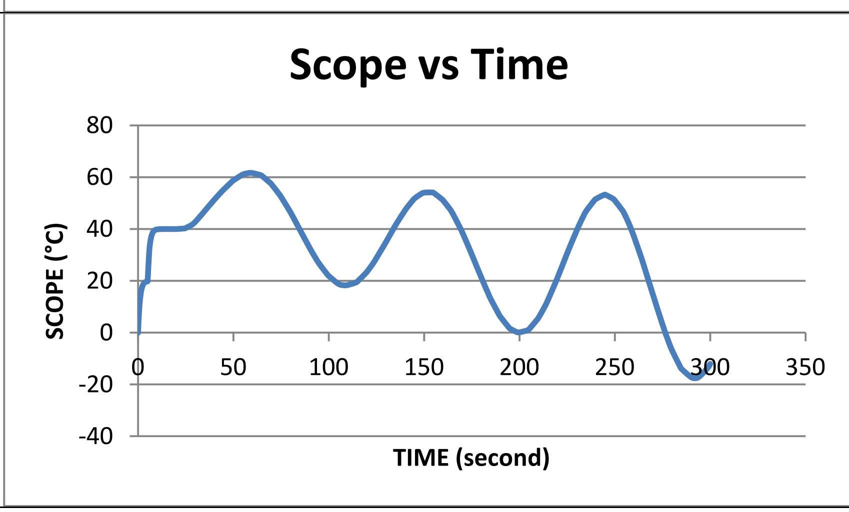


Area of error: 9440.15

Fluctuated to negative value and unstable

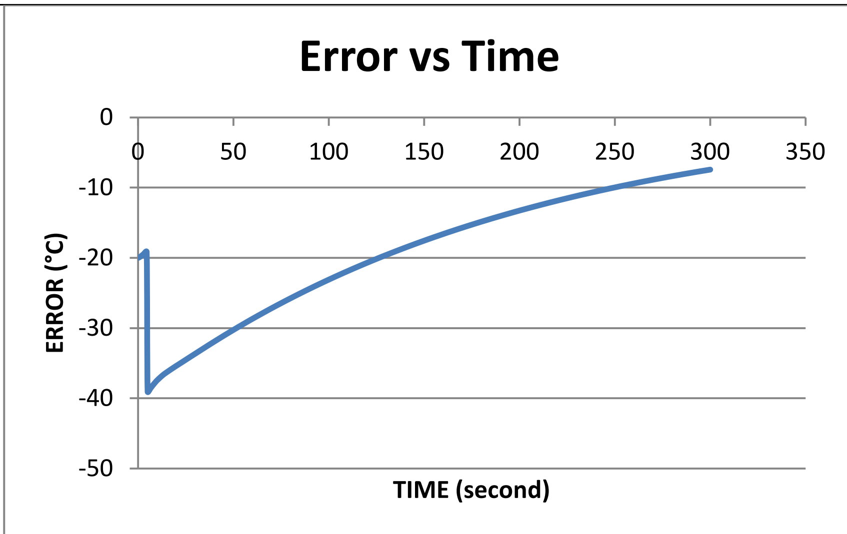


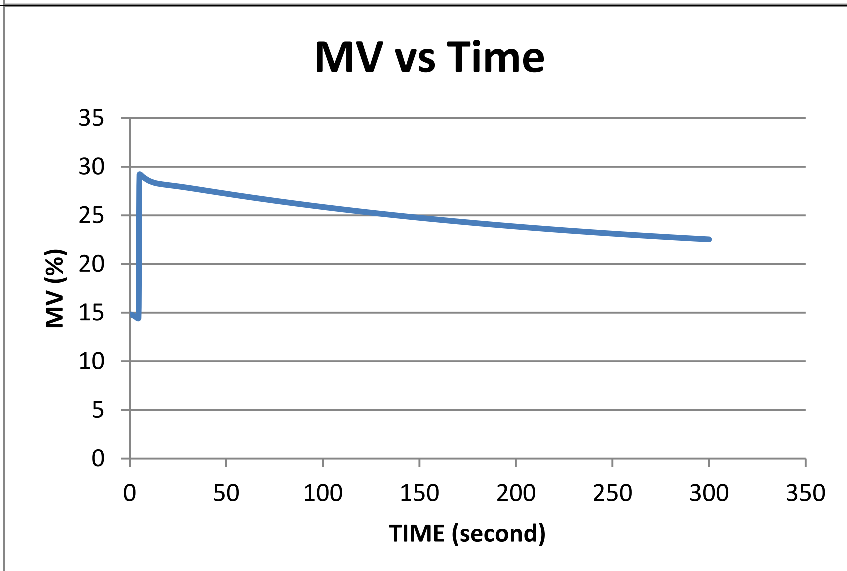
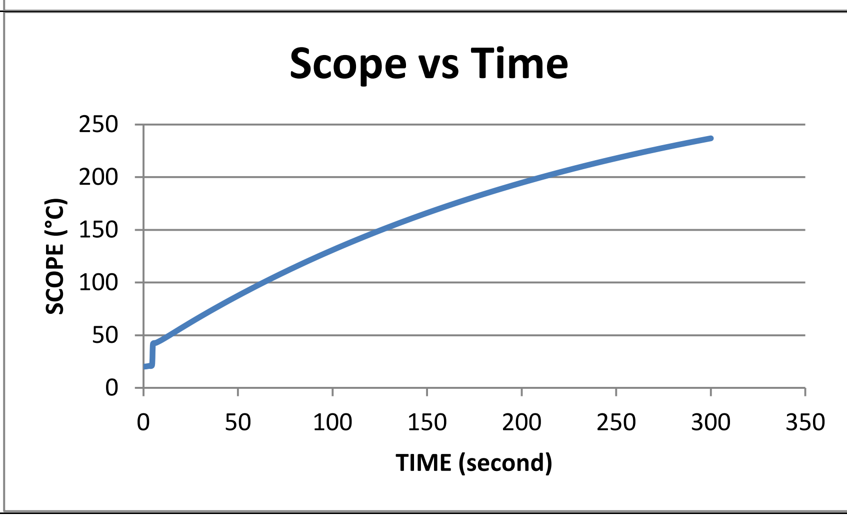
Fluctuated to negative value and unstable



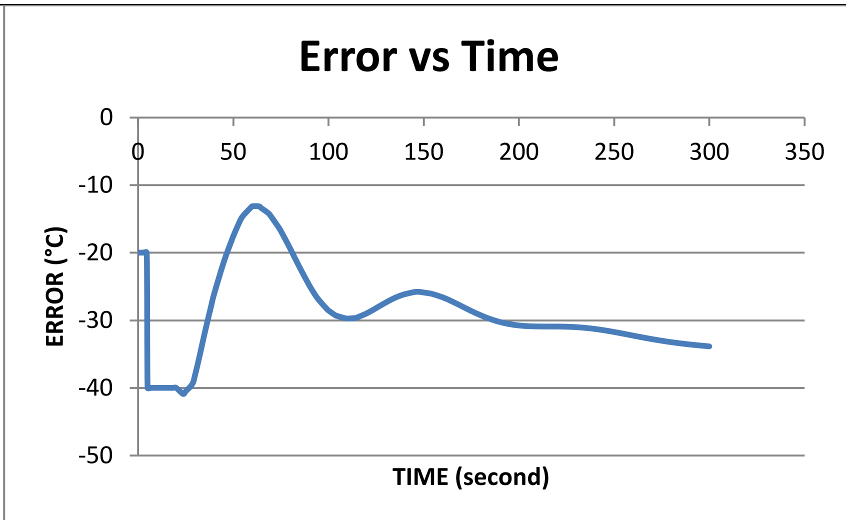
Fluctuated to negative value and unstable

- IMC Control

<table>
<tr><td>
</td><td>Area of error: 5753

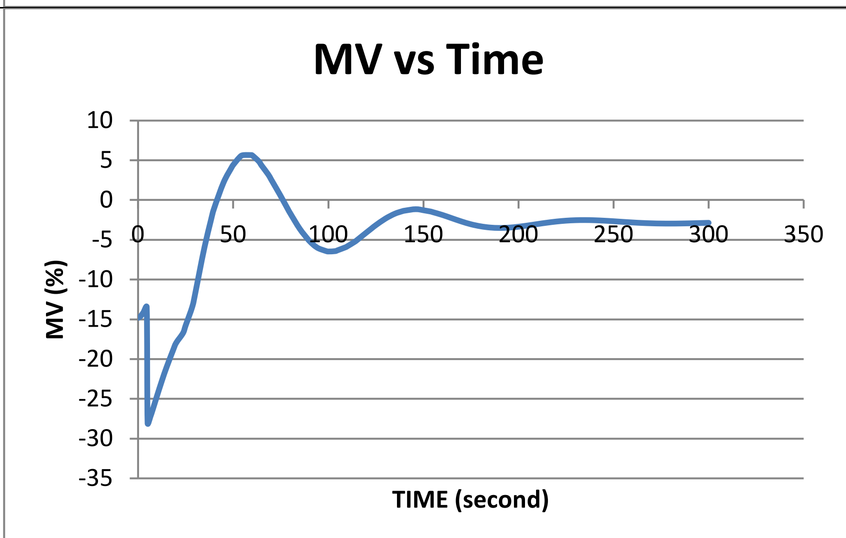
Fluctuated to negative value and unstable</td></tr>
<tr><td>
</td><td>Stable</td></tr>
<tr><td>
</td><td>Stable</td></tr>
</table>

- Smith Control

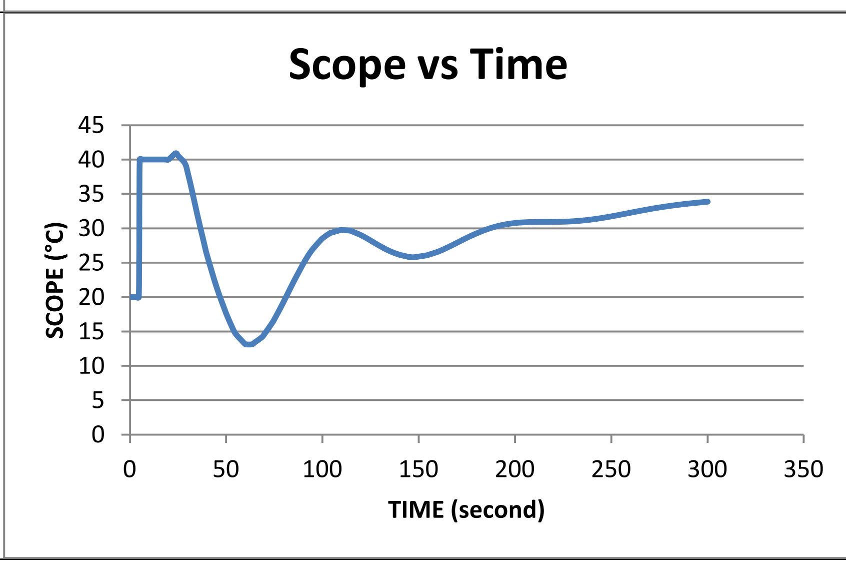


Area of error: 8608.55

Fluctuated to negative value



Fluctuated to negative value at beginning and begin to stable until the end

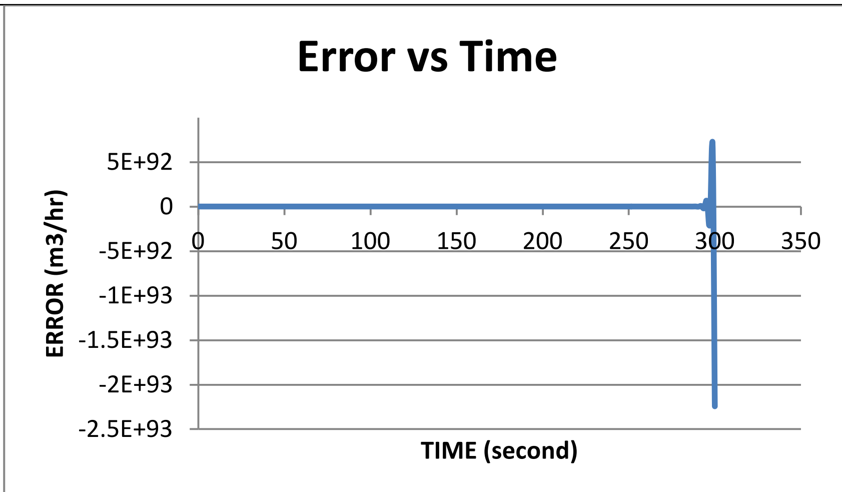


Fluctuated but stable at positive value

7.2 Step

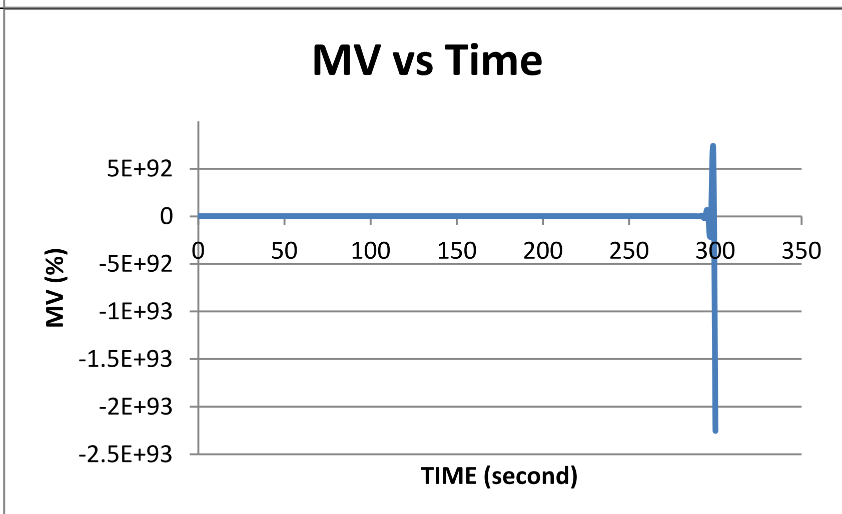
7.2.1 FLOW1

- Cascade Control

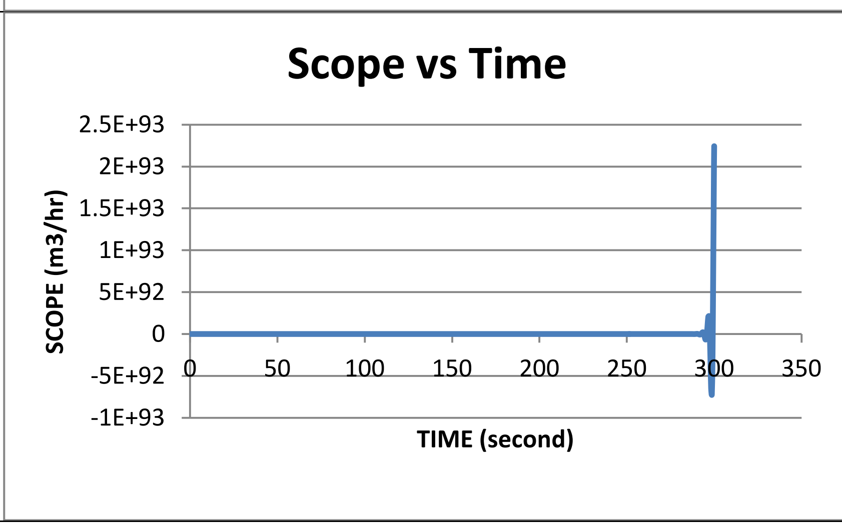


Area of error = 4.02E92

Result is unstable and has negative value.

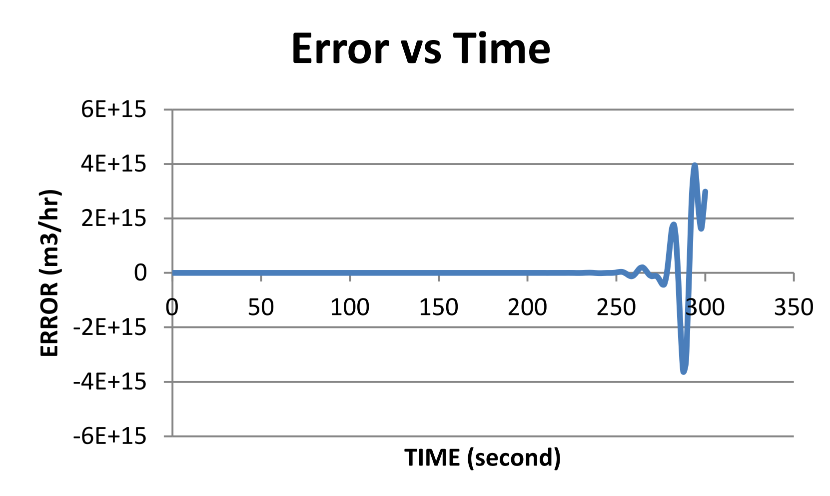


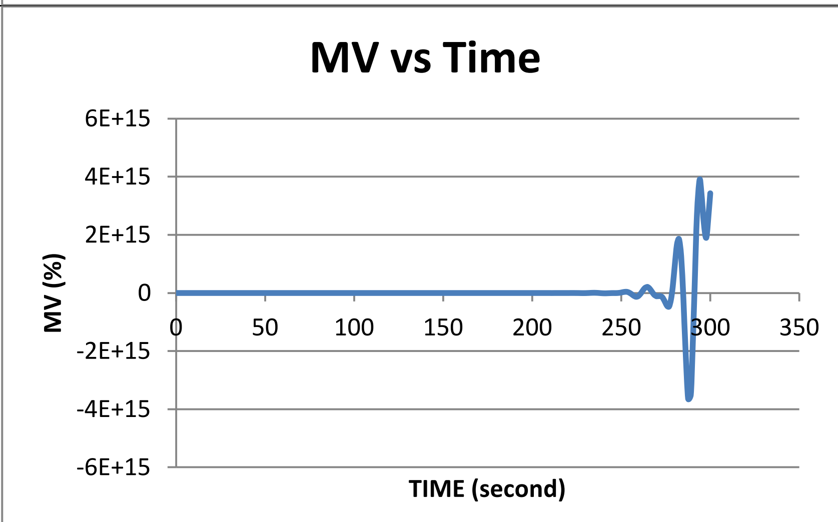
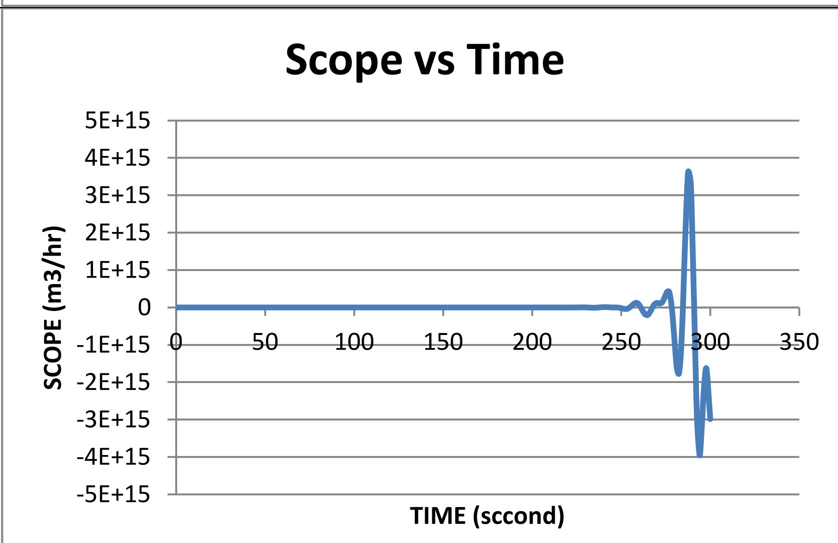
Result is unstable and has negative value.



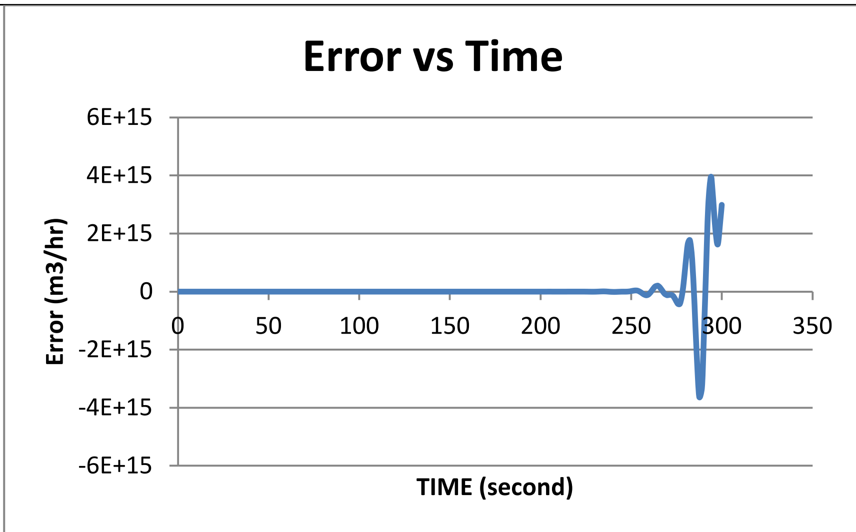
Result is unstable.

- Feedback Control

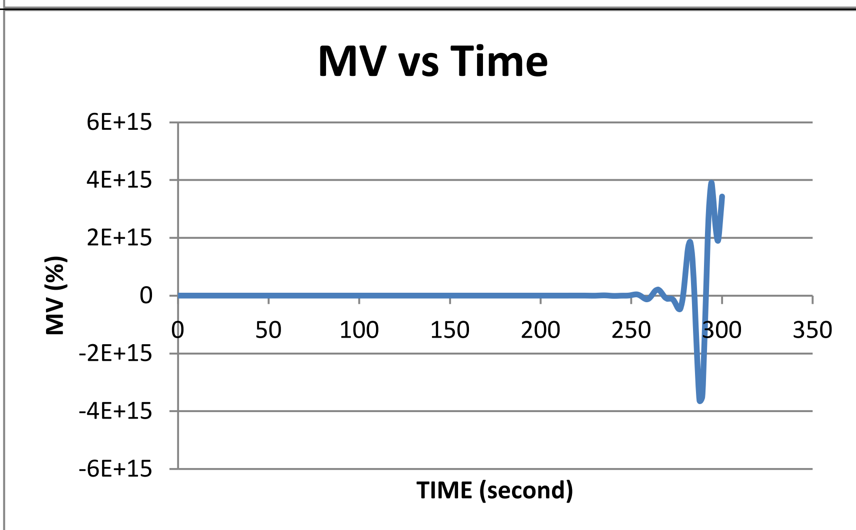
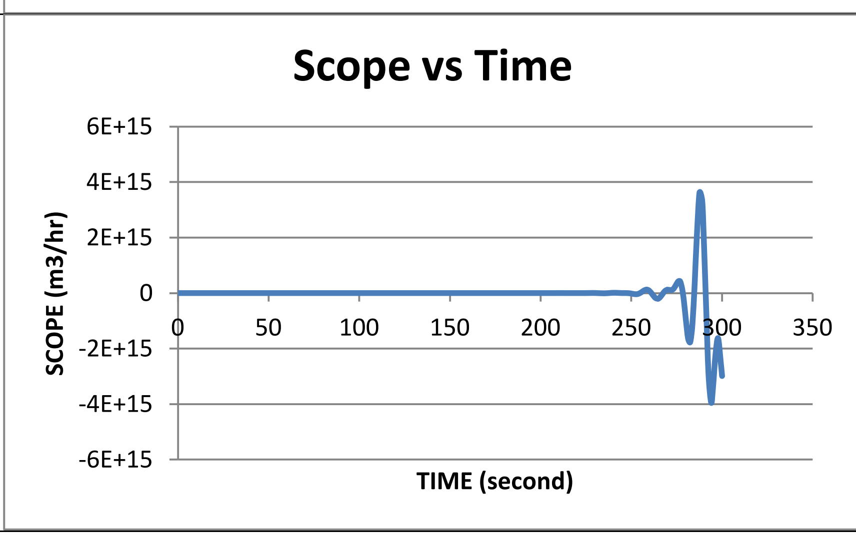
<table>
<tr>
<td>
</td>
<td>Area of error:
1.3593e+16

Maintained stable at the initial and begin to fluctuate at certain point.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the initial and begin to fluctuate at certain point.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the initial and begin to fluctuate at certain point.</td>
</tr>
</table>

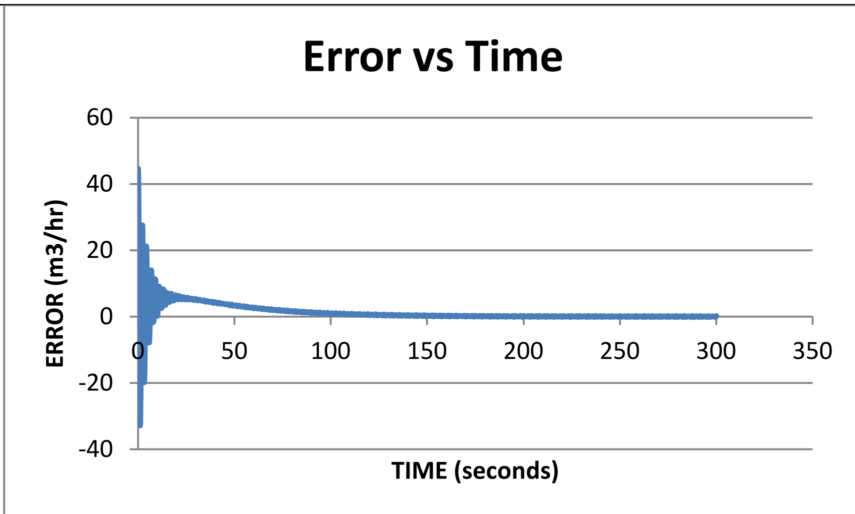
- Feedforward-feedback Control

<table>
<tr>
<td>
</td>
<td>Area of error =

1.36E+16

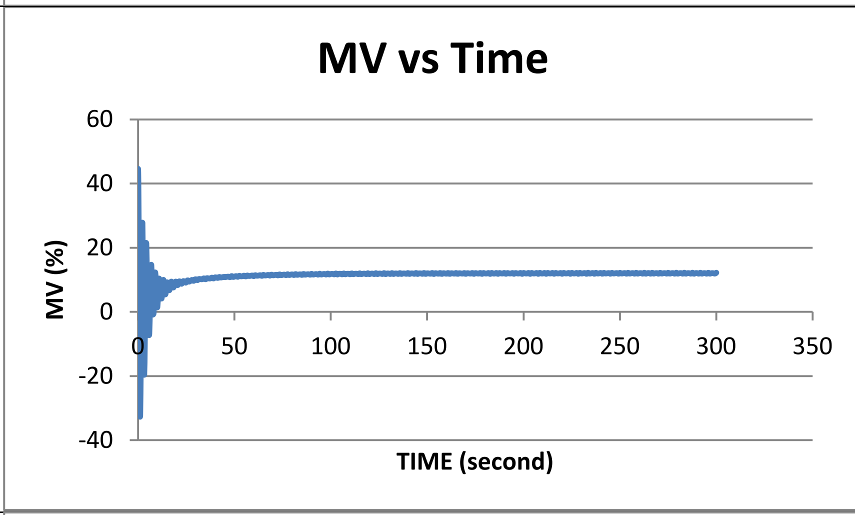
Maintained stable at the initial and begin to fluctuate at certain point.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the initial and begin to fluctuate at certain point.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the initial and begin to fluctuate at certain point.</td>
</tr>
</table>

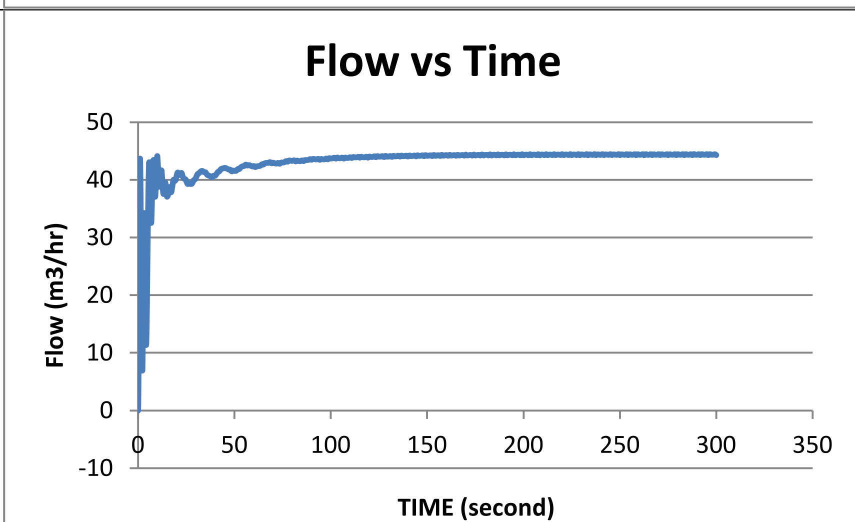
- IMC Control

<table>
<tr>
<td>


</td>
<td>
Area of error =

367.392

Fluctuated at the beginning and then maintained stable until the end.
</td>
</tr>
<tr>
<td>


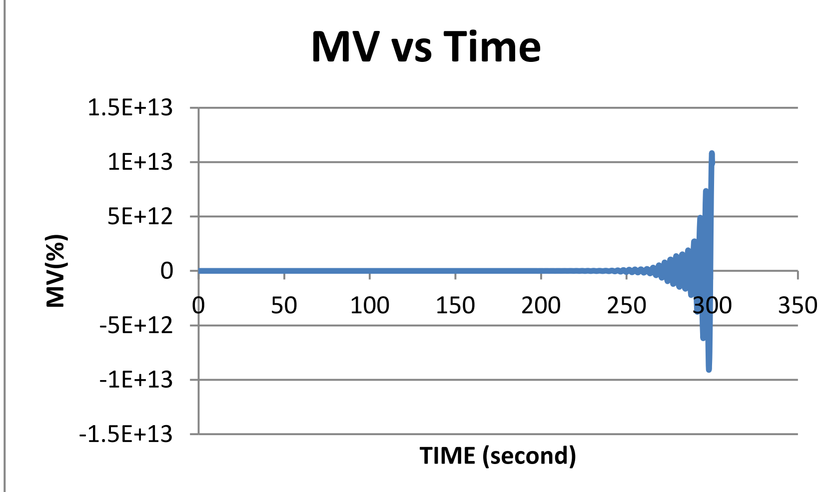
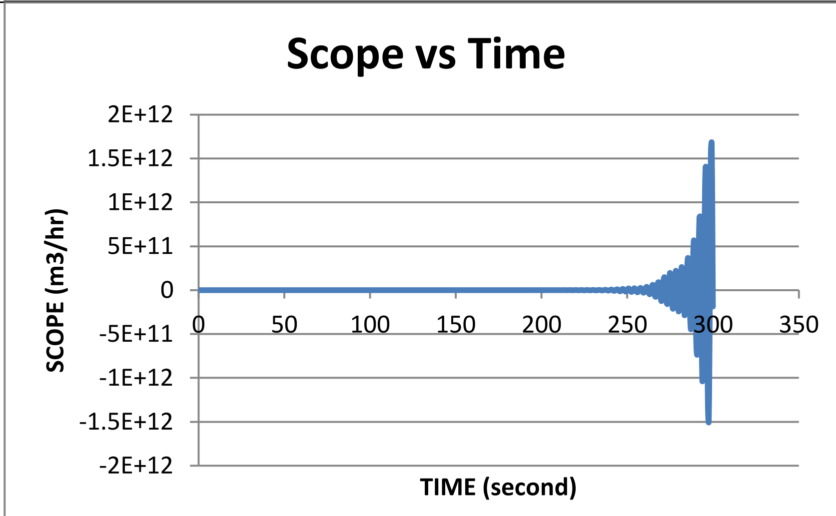
</td>
<td>
Fluctuated at the beginning and then maintained stable until the end.
</td>
</tr>
<tr>
<td>


</td>
<td>
Fluctuated at the beginning and then maintained stable until the end.
</td>
</tr>
</table>

- Smith Control

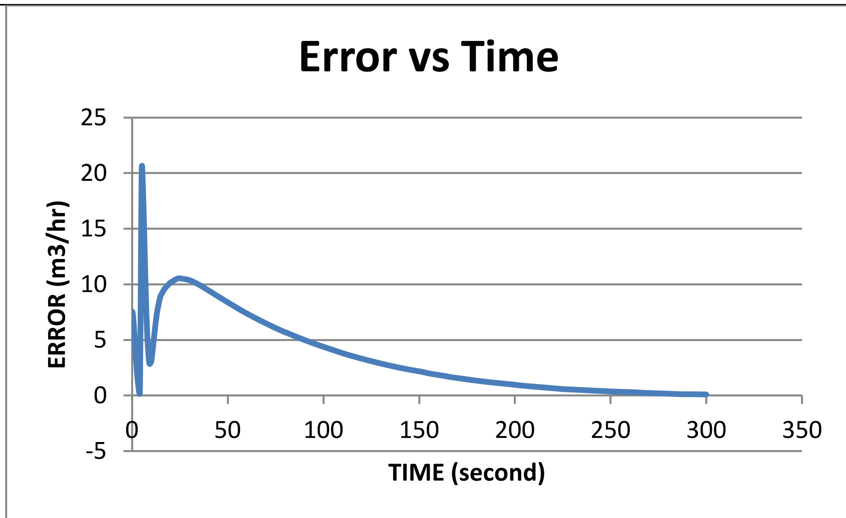
<table>
<tr>
<td>
</td>
<td>Area of error =

-1.74E+12

Maintained stable at the beginning and begin to fluctuate at certain point.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the beginning and begin to fluctuate at certain point.</td>
</tr>
<tr>
<td>
</td>
<td>Maintained stable at the beginning and begin to fluctuate at certain point.</td>
</tr>
</table>

7.2.2 FLOW2

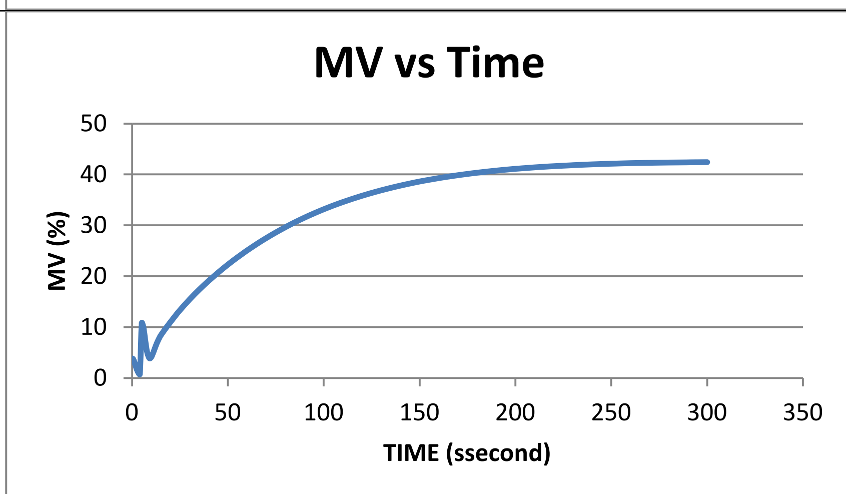
- Cascade Control



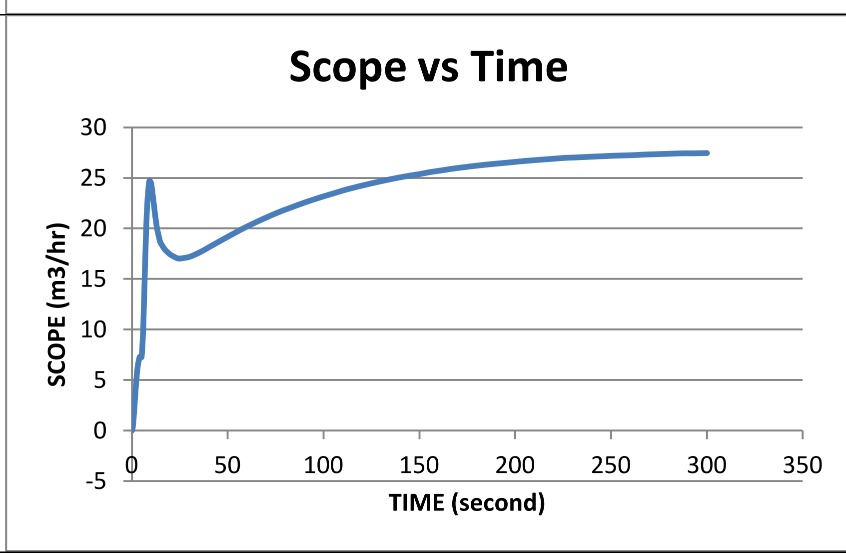
Area of error =

1.03E+03

Fluctuated at the beginning and then maintained stable until the end.

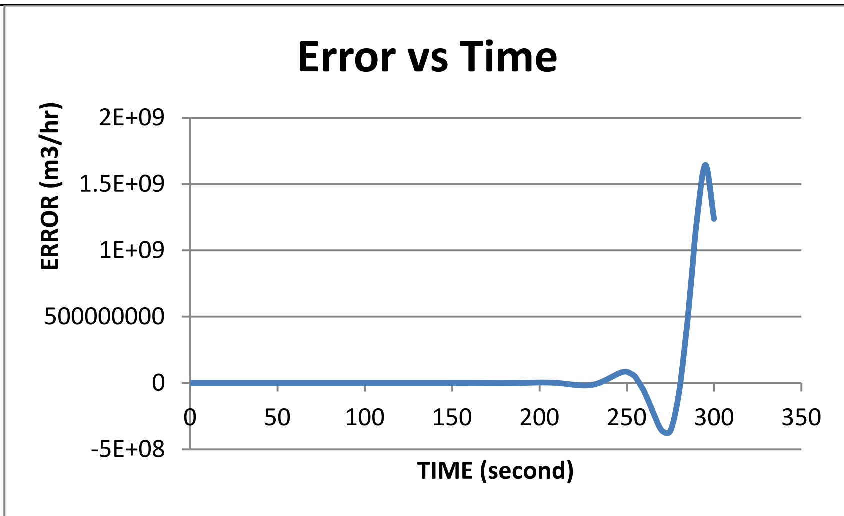


Fluctuated at the beginning and then maintained stable until the end.



Fluctuated at the beginning and then maintained stable until the end.

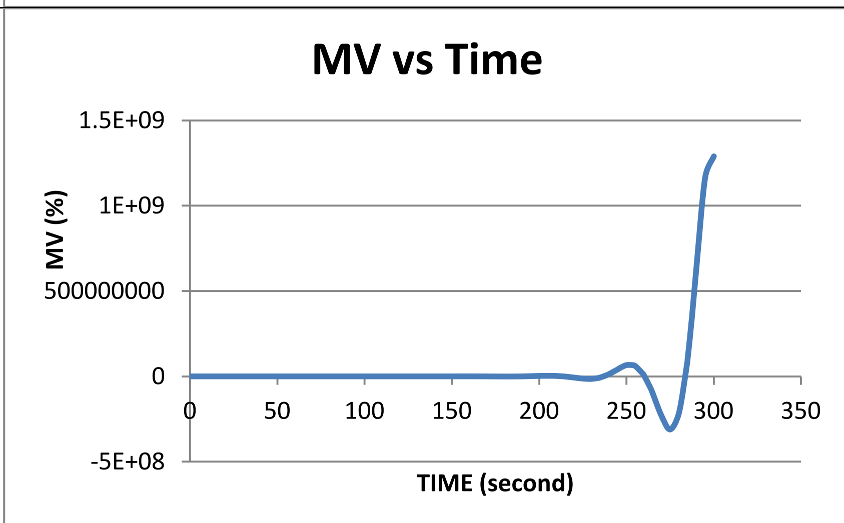
- Feedback Control



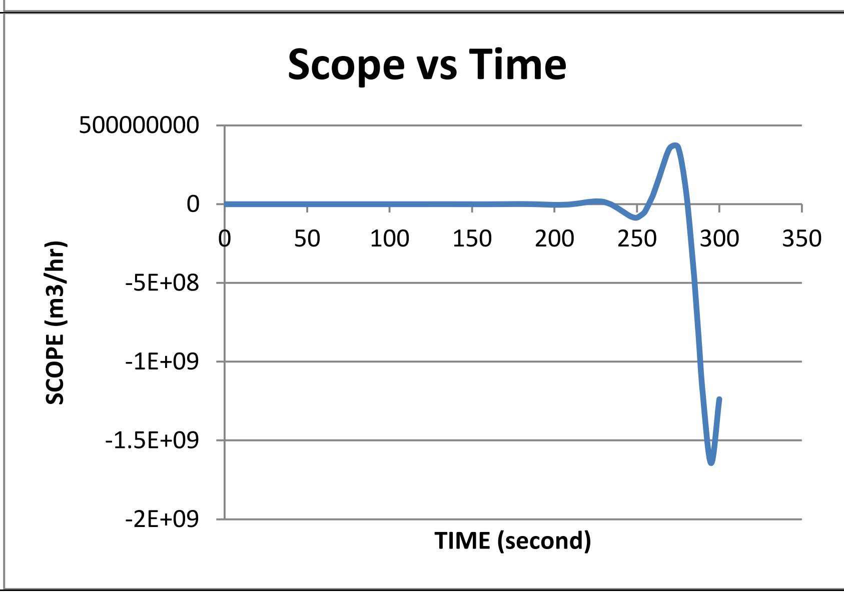
Area of error =

1.55E+10

Not stable

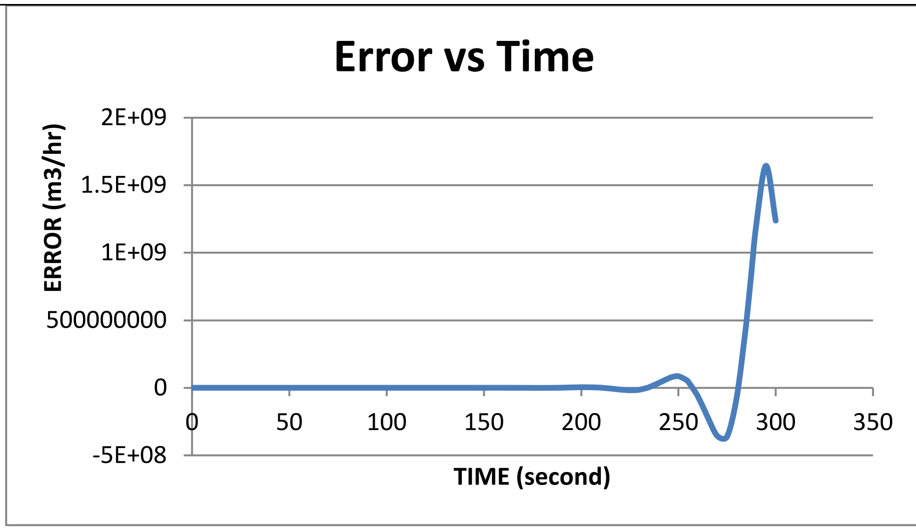


Not stable

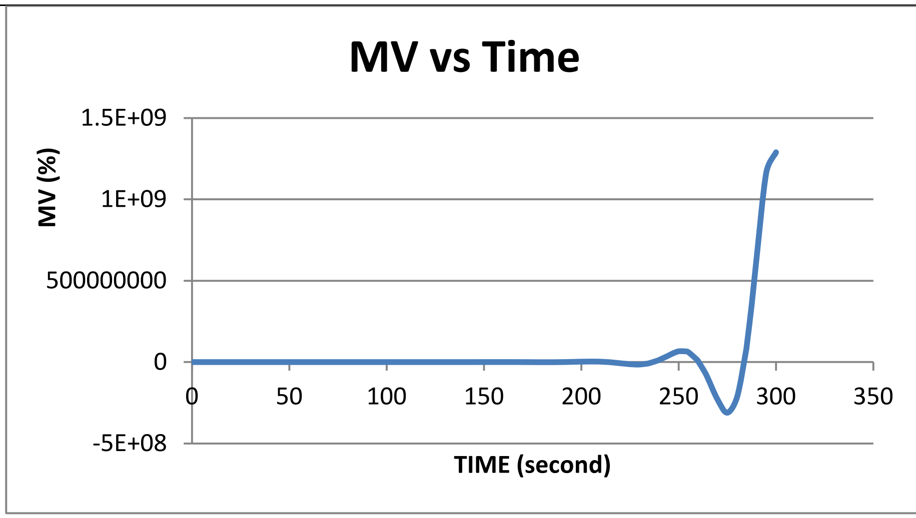
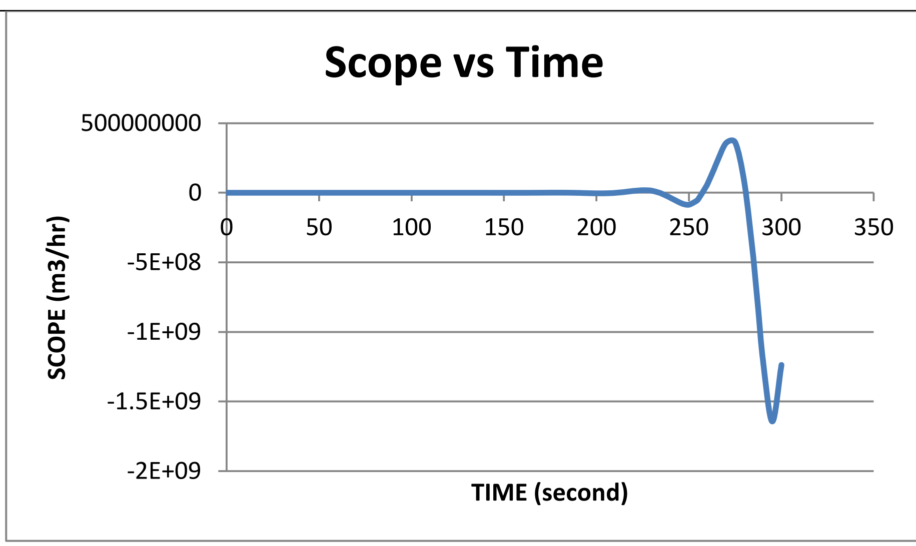


Not stable

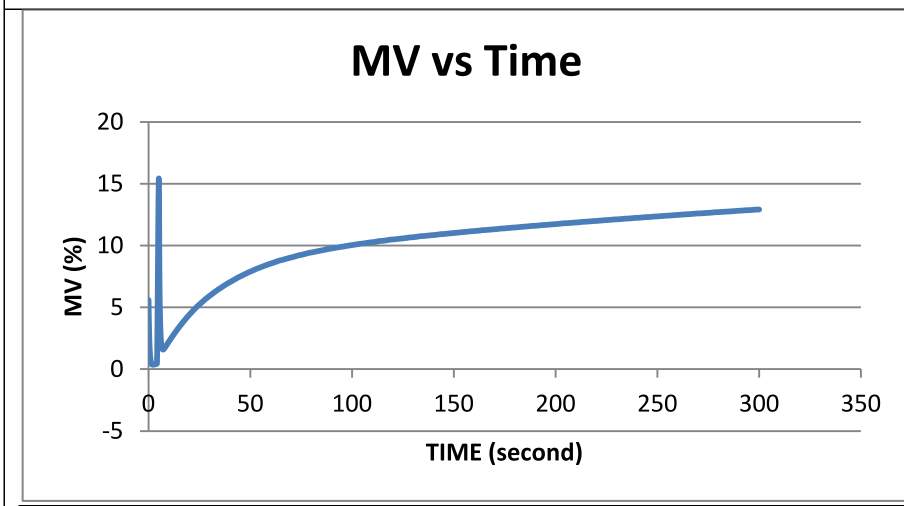
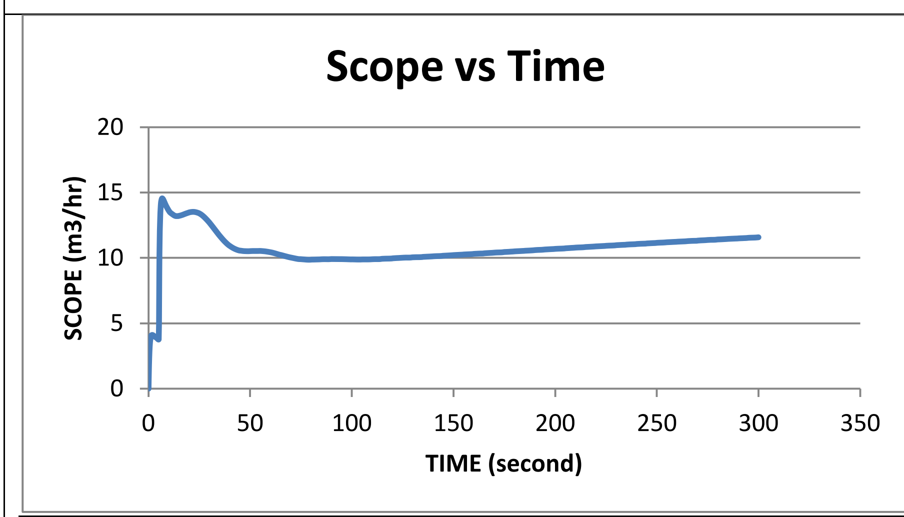
- Feedfeedforward-feedback

<table>
<tr>
<td>
</td>
<td>Area of error
=

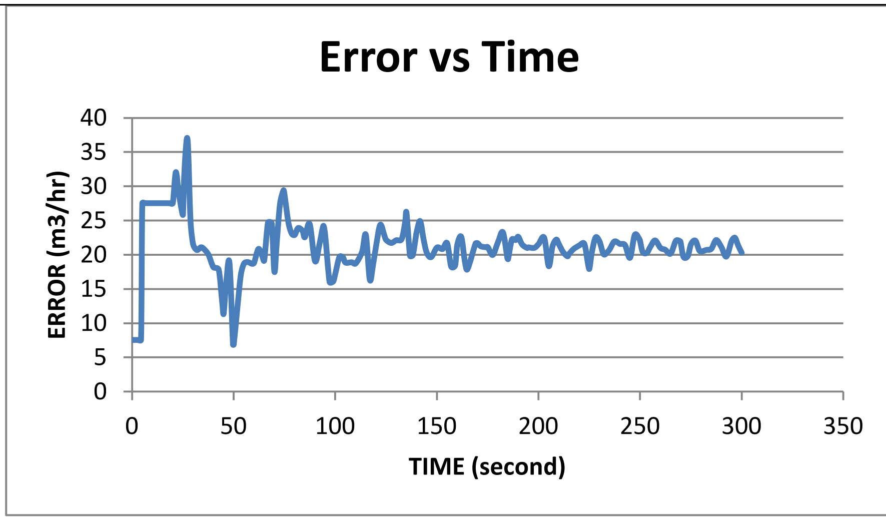
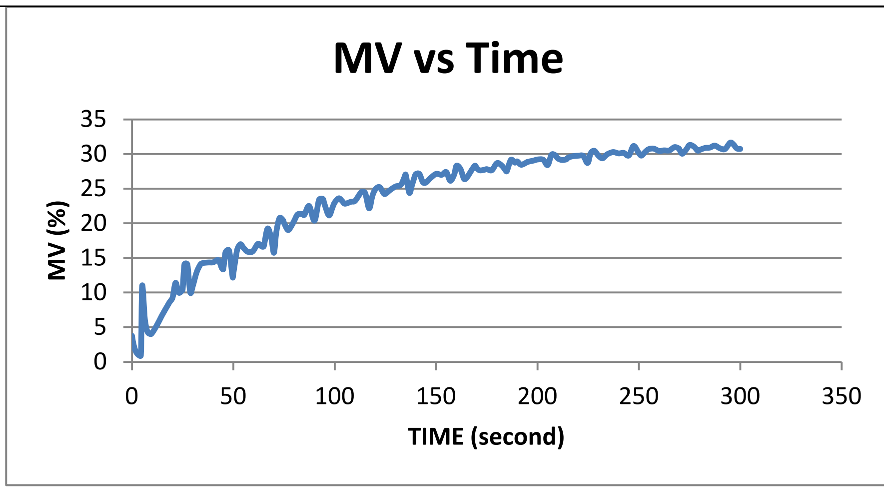
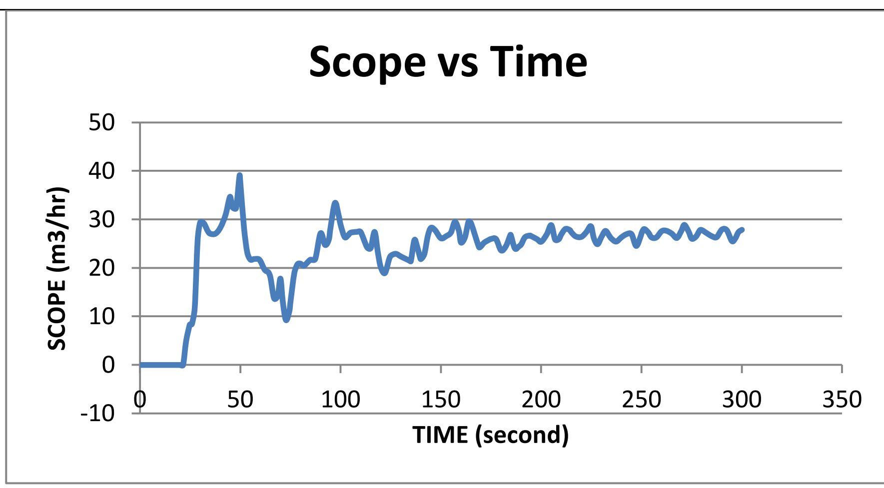
1.55E+10

Not stable</td>
</tr>
<tr>
<td>
</td>
<td>Not stable</td>
</tr>
<tr>
<td>
</td>
<td>Not stable</td>
</tr>
</table>

- IMC Control

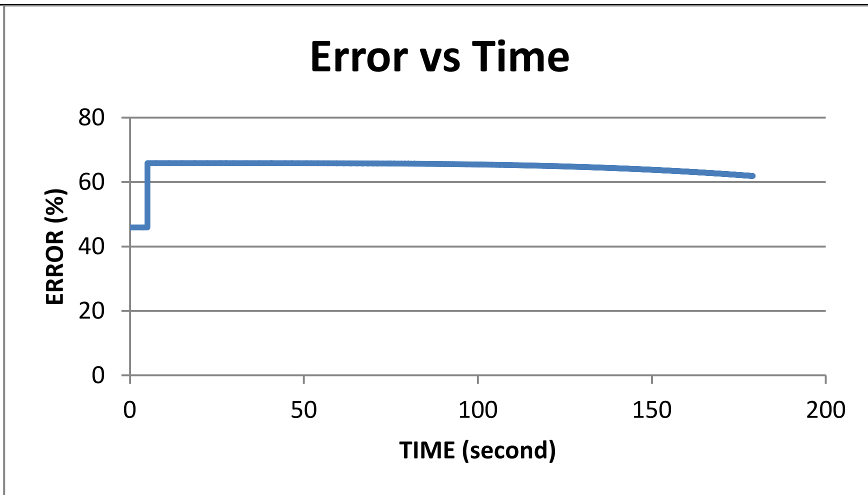
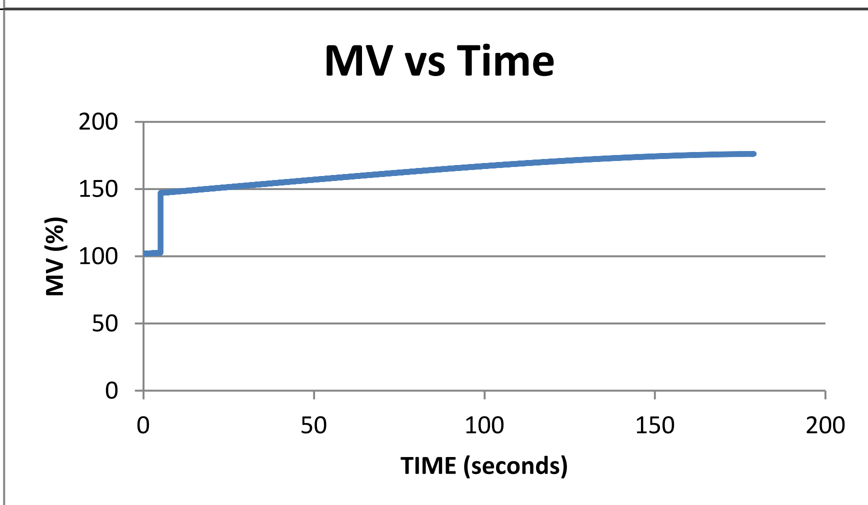
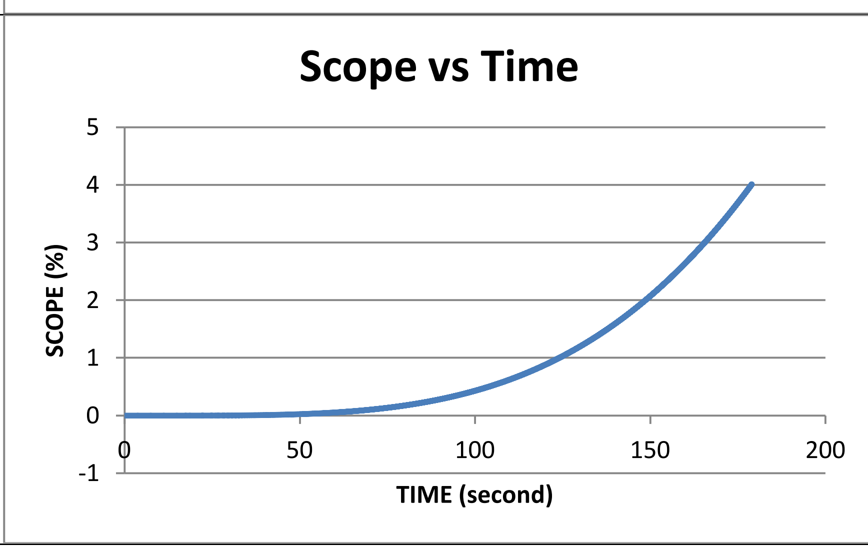
	Area of error = 2.58E+03 Fluctuated at the beginning and then maintained stable until the end
	Fluctuated at the beginning and then maintained stable until the end
	Fluctuated at the beginning and then maintained stable until the end

- Smith Control

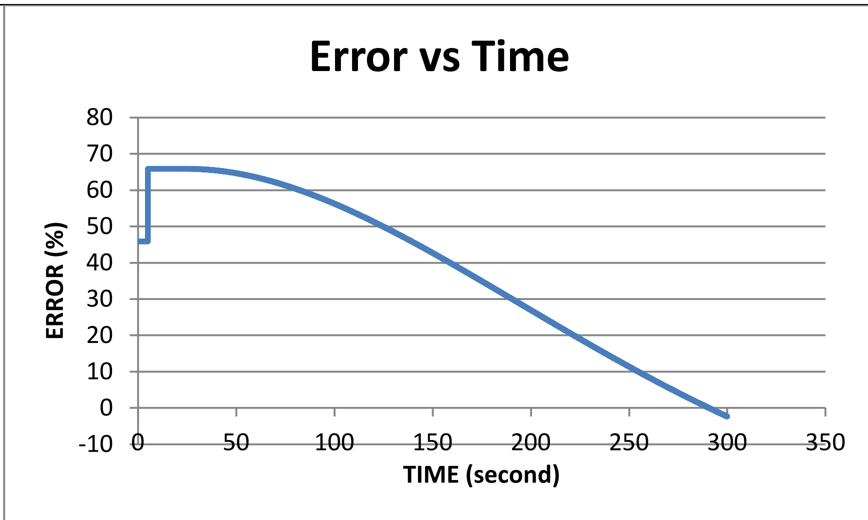
	Area of error = 6.37E+03 Fluctuating and unstable
	Fluctuating and unstable
	Fluctuating and unstable

7.2.3 LEVEL 1

- Cascade Control

	Area of error = 1.80E+04 Stable
	Stable
	Stable

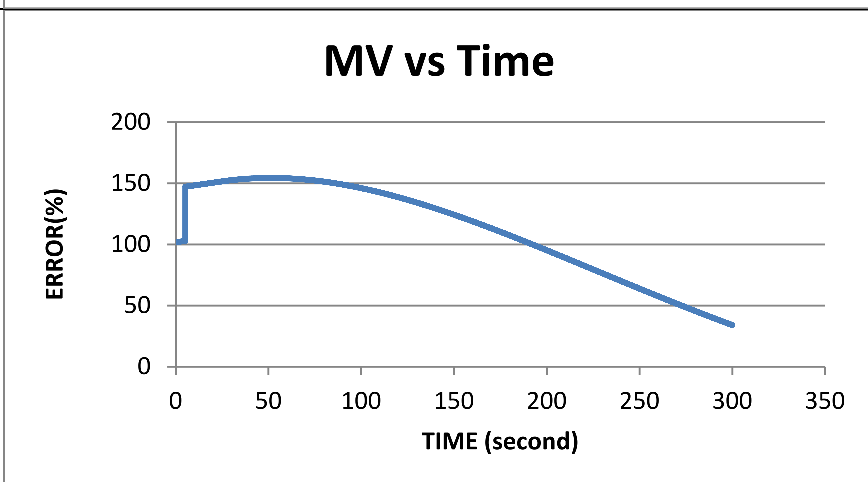
- Feedback Control



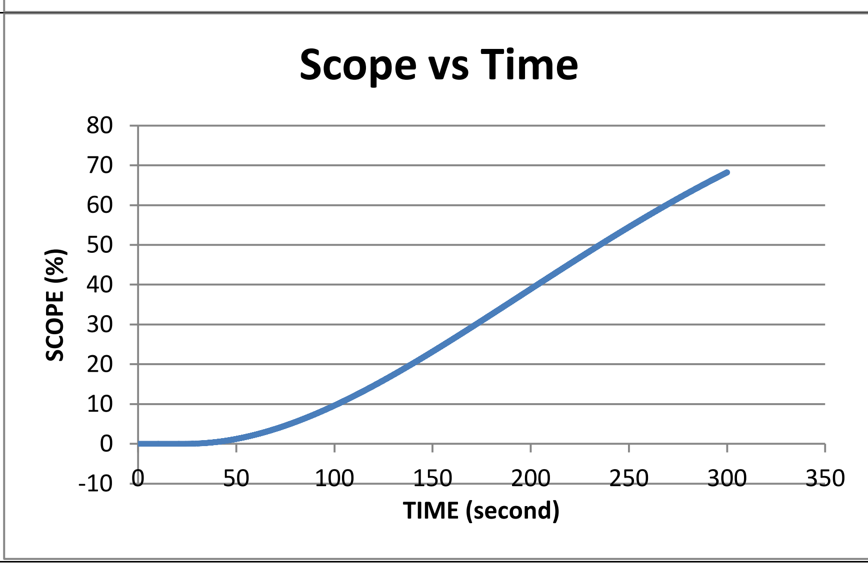
Area of error =

1.16E+04

Stable but the value keep decreasing until zero

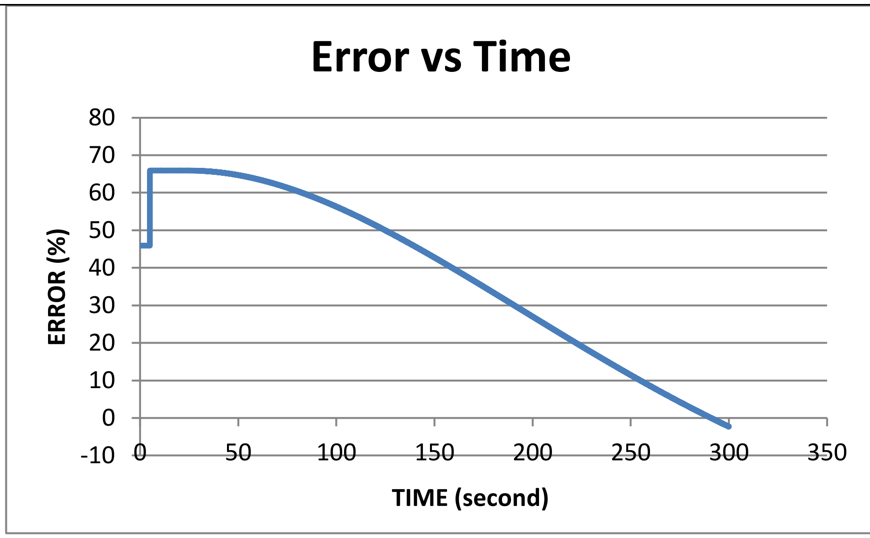
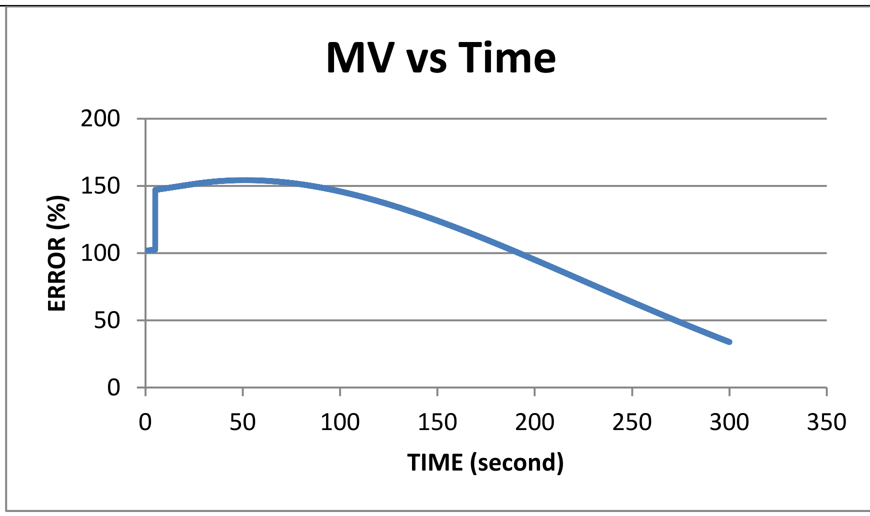
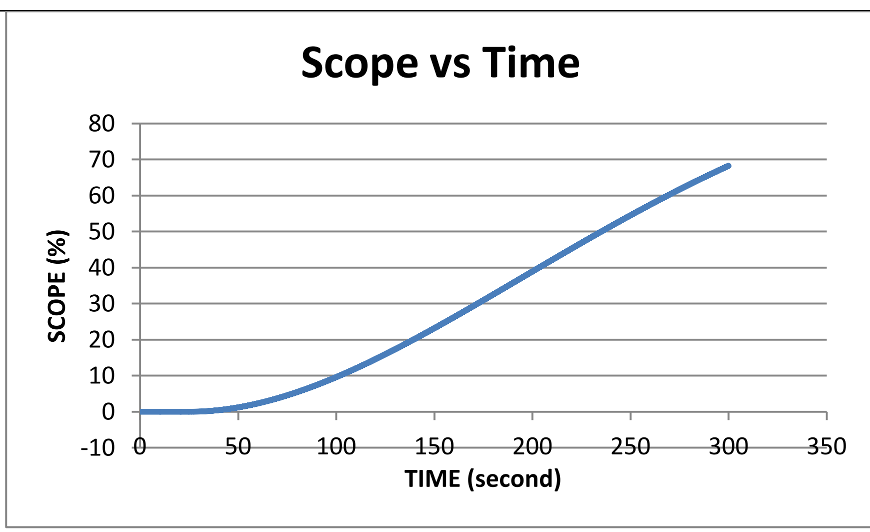


Stable but the value keep decreasing until zero



Stable but the value keep increasing

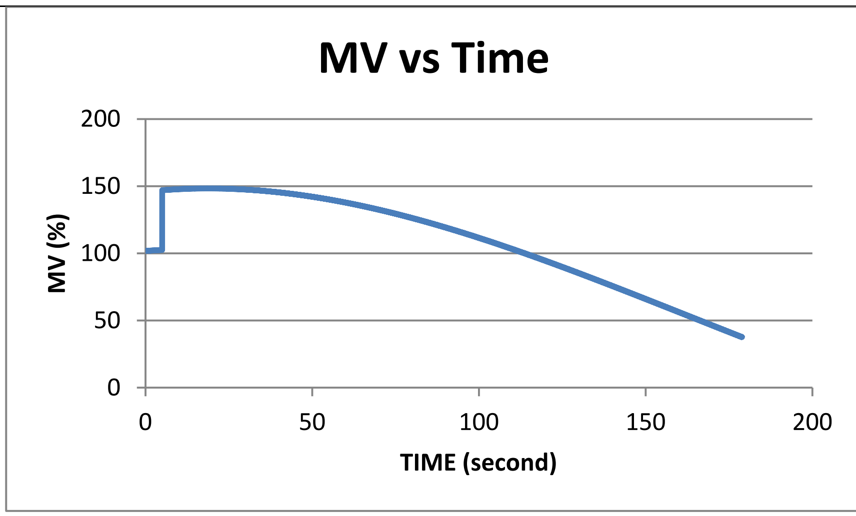
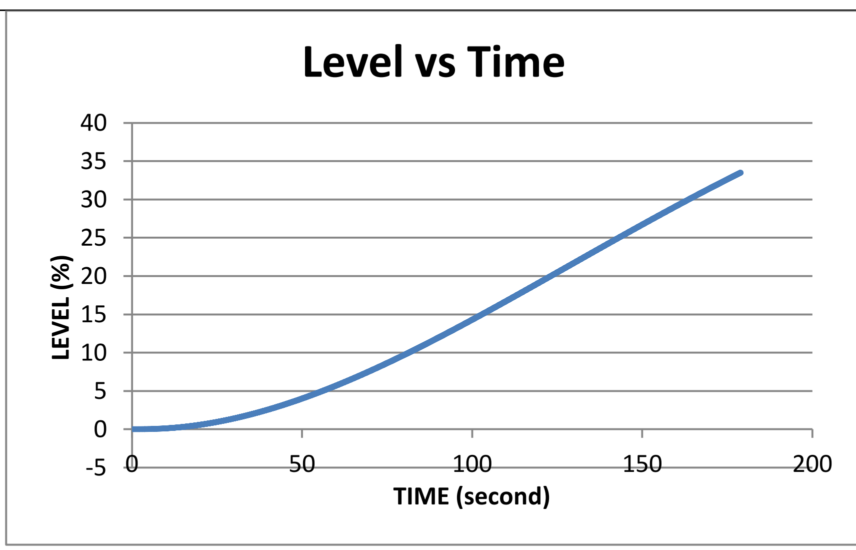
- Feedforward-feedback Control

	Area of error = 1.16E+04 Stable but the value keep decreasing until zero
	Stable but the value keep decreasing until zero
	Stable but the value keep increasing

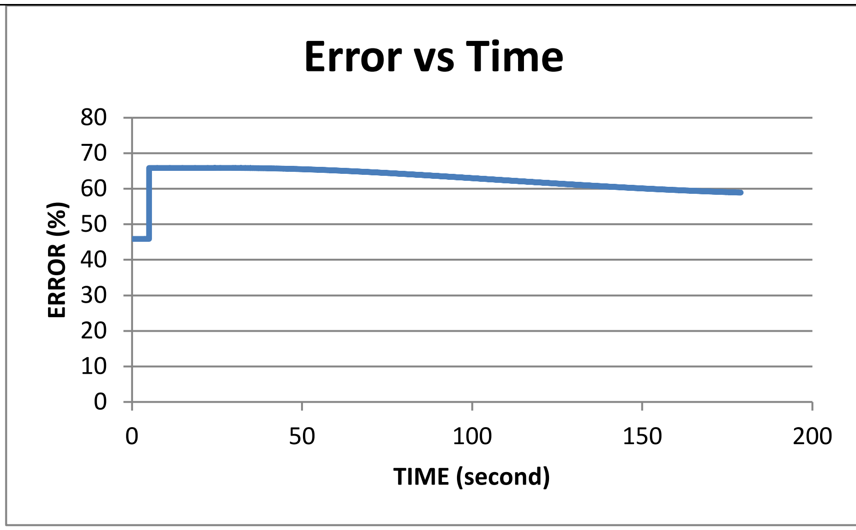
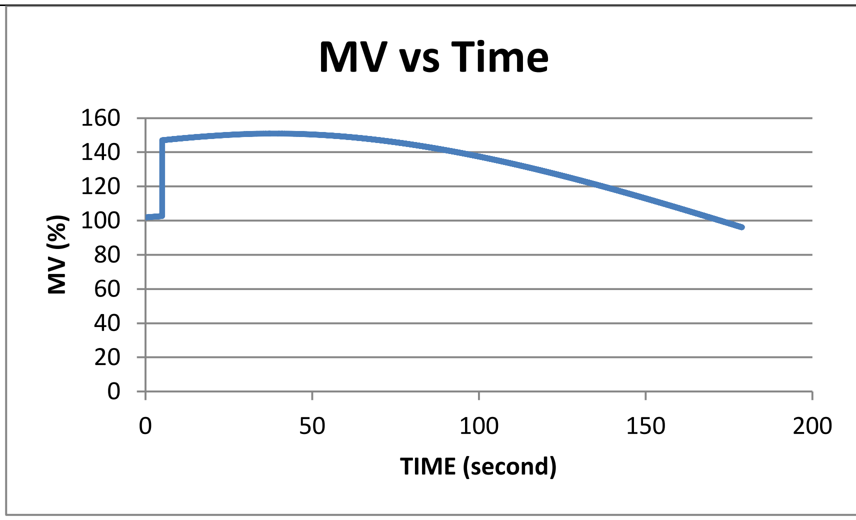
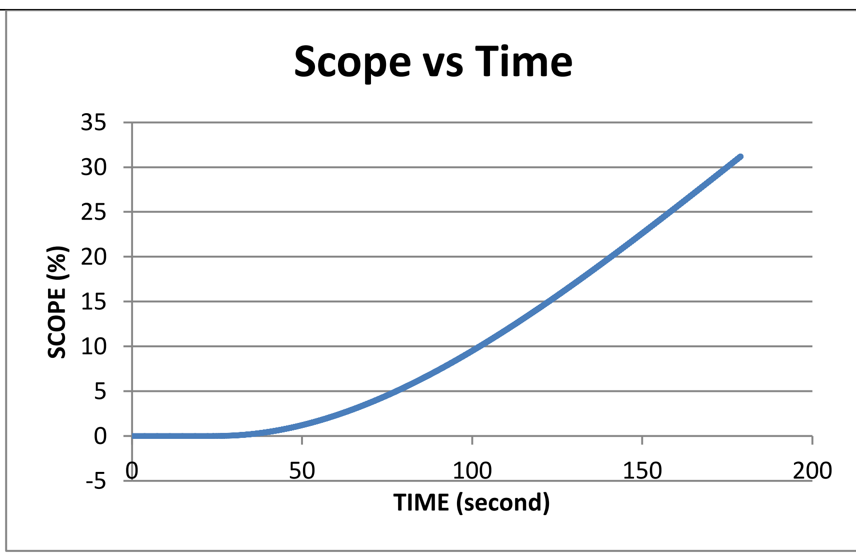
- IMC Control

<table>
<tr>
<td>
</td>
<td>Area of error =

5.52E+03

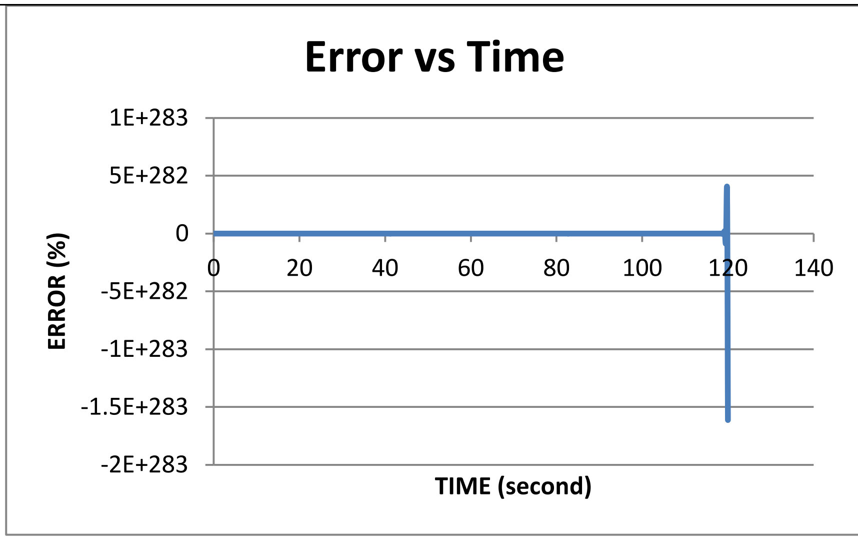
Stable but the value keep decreasing until zero</td>
</tr>
<tr>
<td>
</td>
<td>Stable but then the value keep decreasing until zero</td>
</tr>
<tr>
<td>
</td>
<td>Stable but then the value keep increasing</td>
</tr>
</table>

- Smith Control

	Area of error = 1.84E+04 Stable
	Stable
	Maintained stable and then the value keep increasing

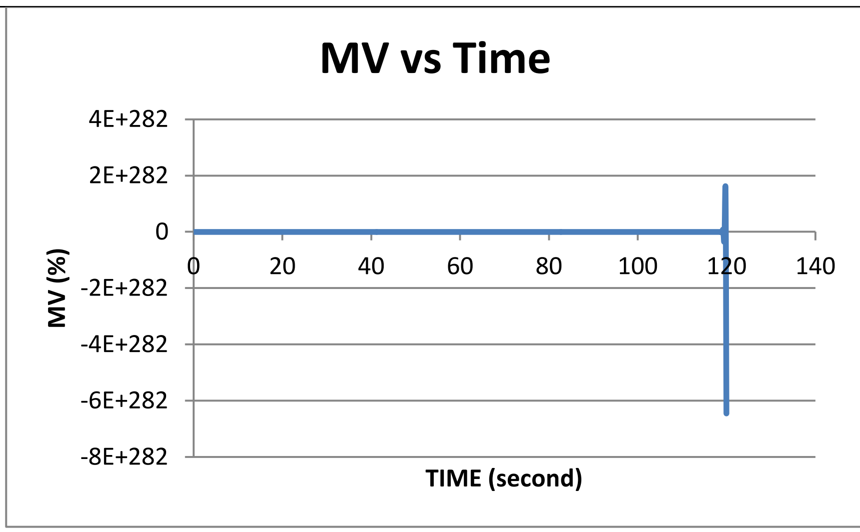
7.2.4 LEVEL 2

- Cascade Control

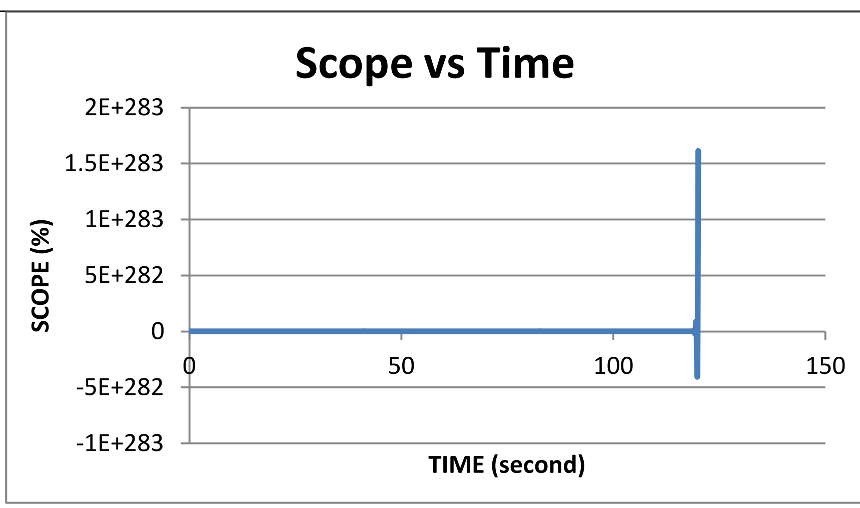


Area of error : 1.9E+285

Unstable

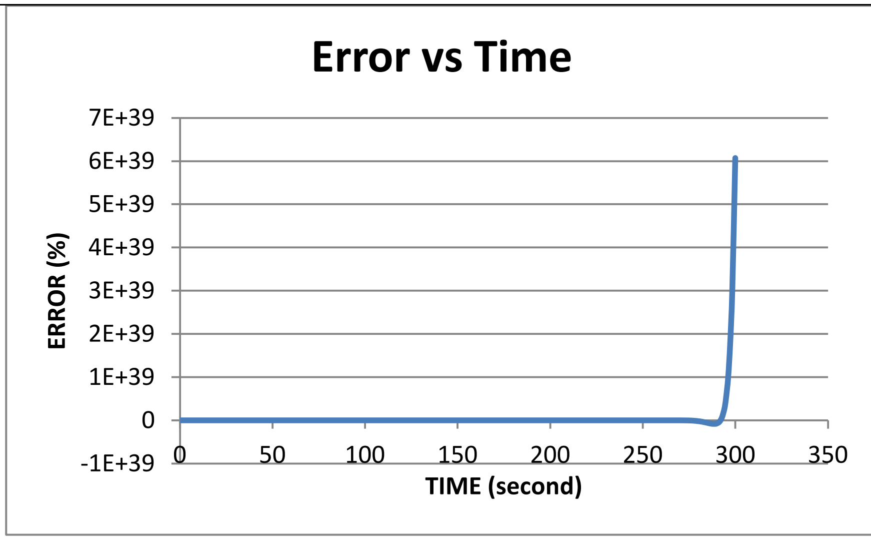
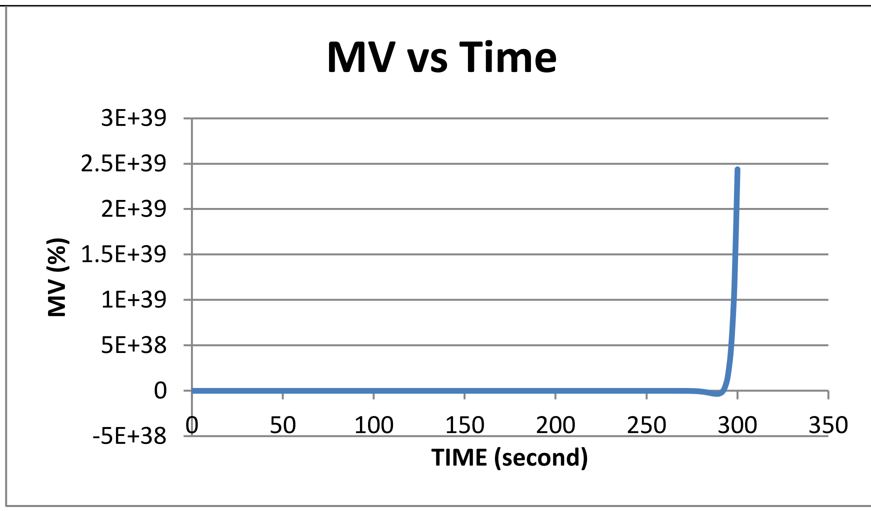
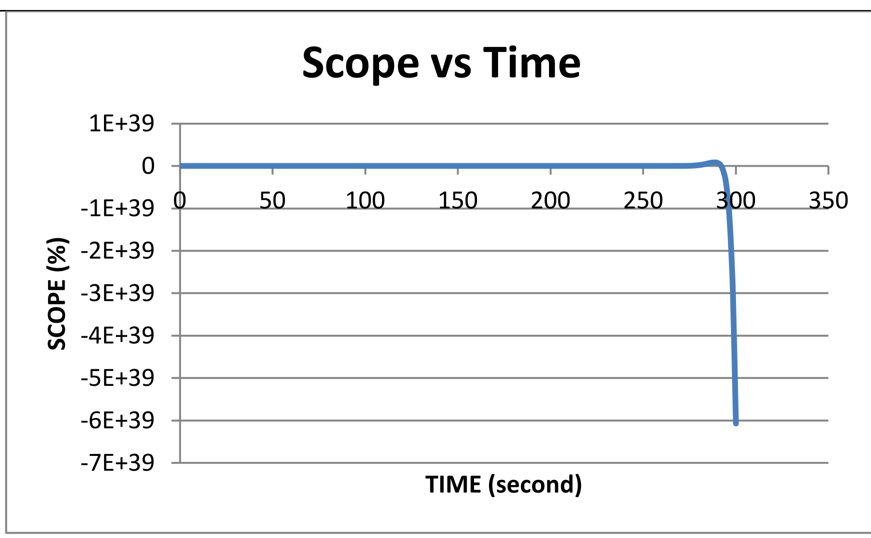


Unstable

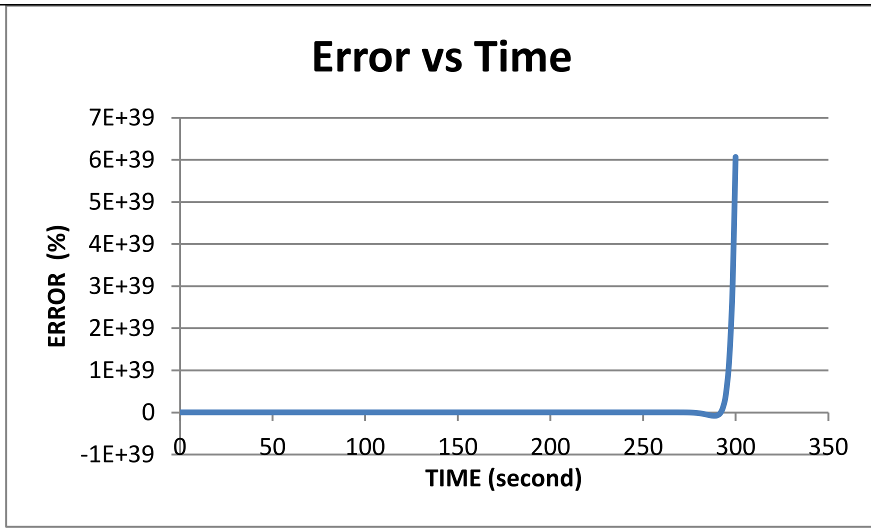
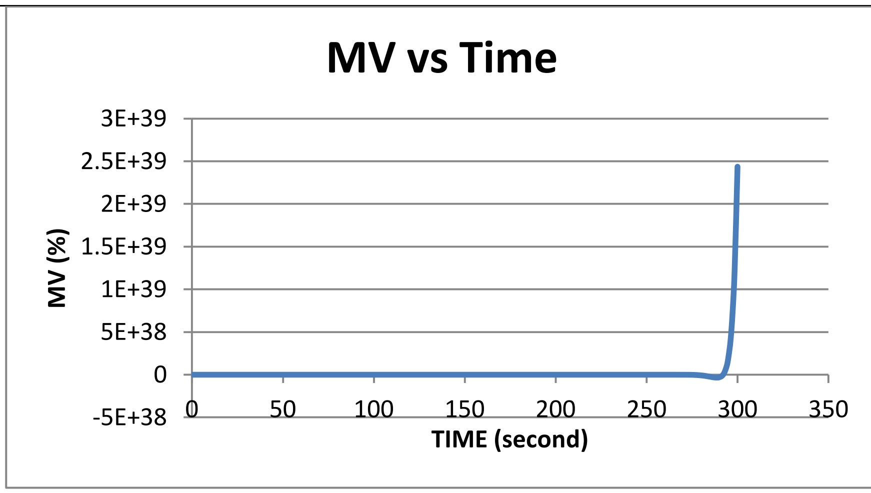
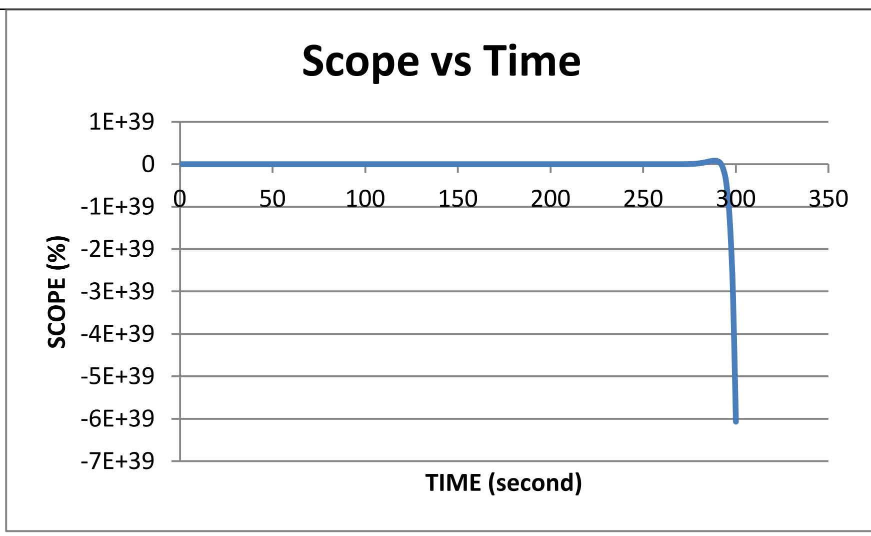


Unstable

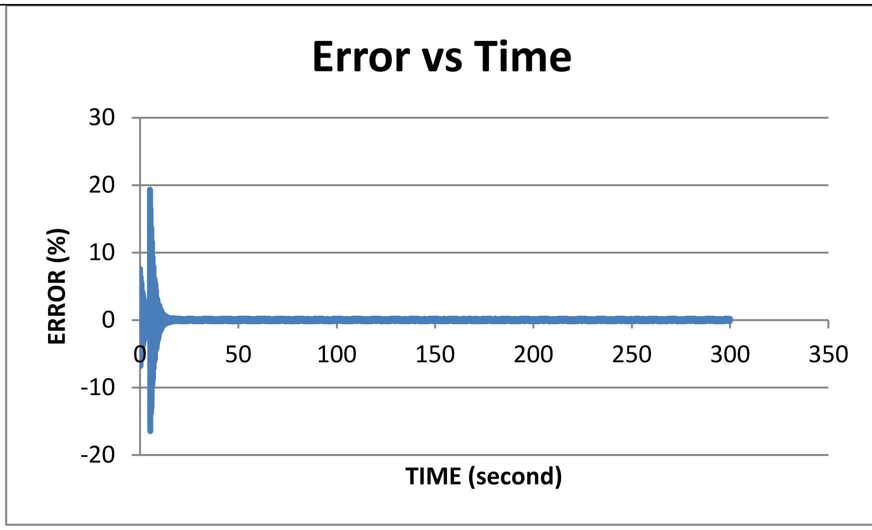
- Feedback Control

	Area of error = 1.23E+40 Unstable
	Unstable
	Unstable

- Feedforward-feedback Control

	Area of error = 1.23E+40 Unstable
	Unstable
	Unstable

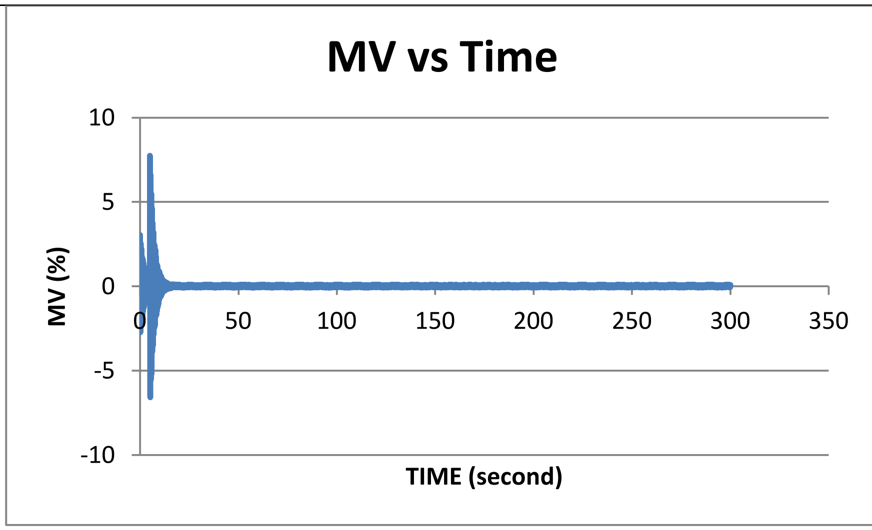
- IMC Control



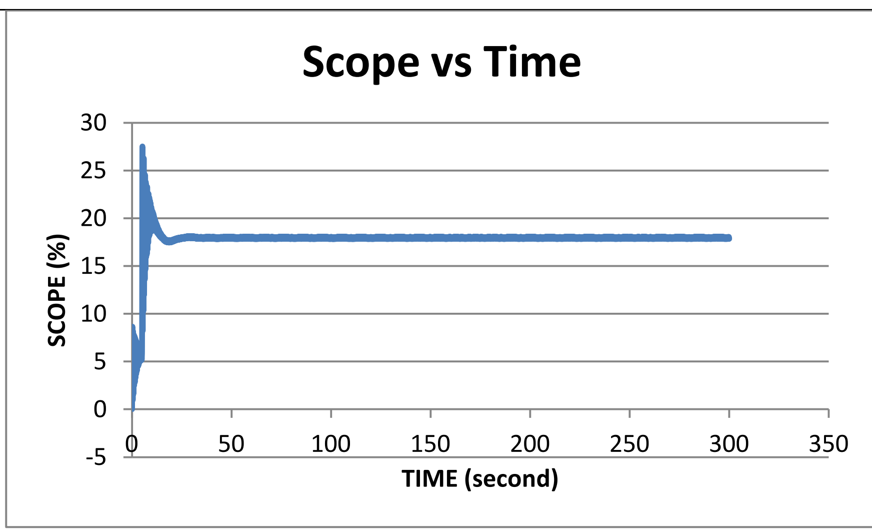
Area of error =

2.8824

Fluctuating at the beginning and then maintained stable.

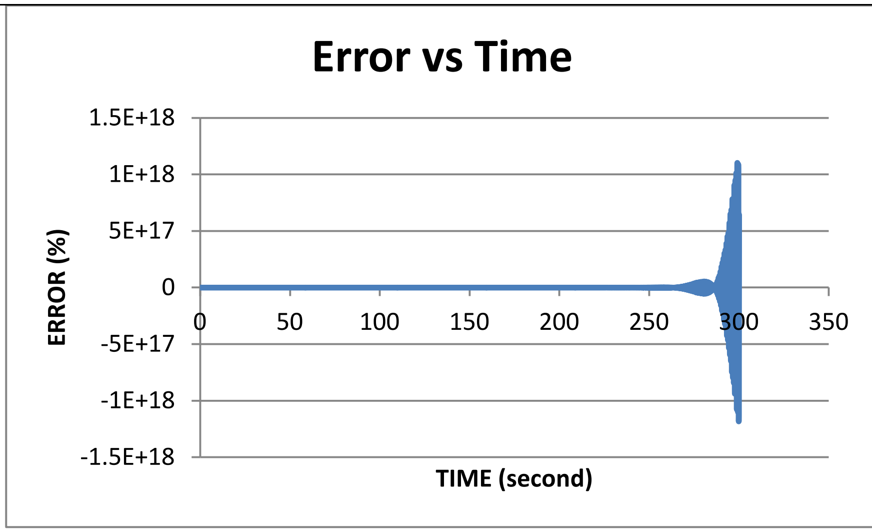


Fluctuating at the beginning and then maintained stable.



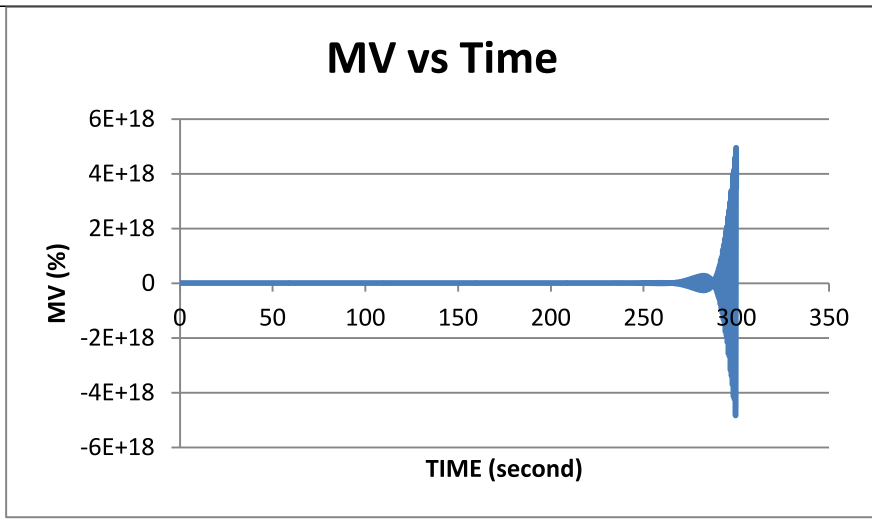
Fluctuating at the beginning and then maintained stable.

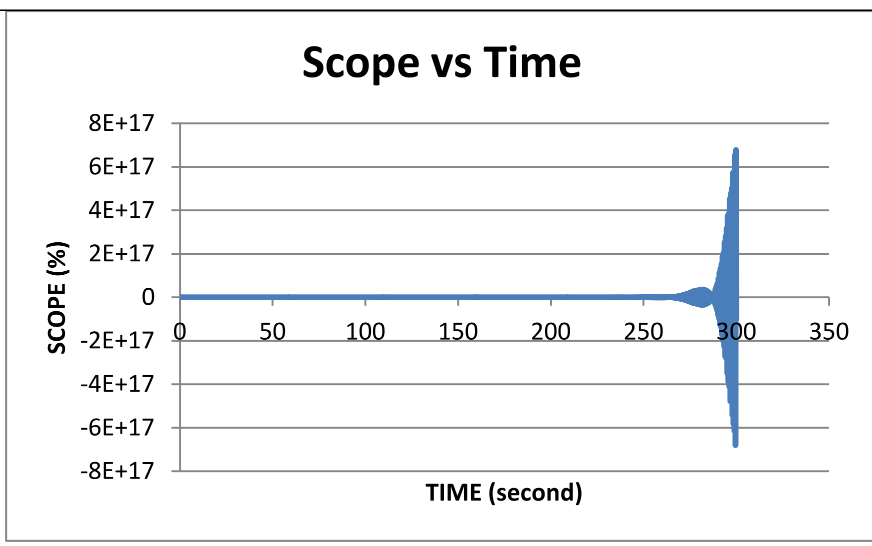
- Smith Control

<table>
<tr>
<td>


</td>
<td>
Area of error =

-8.02E+16

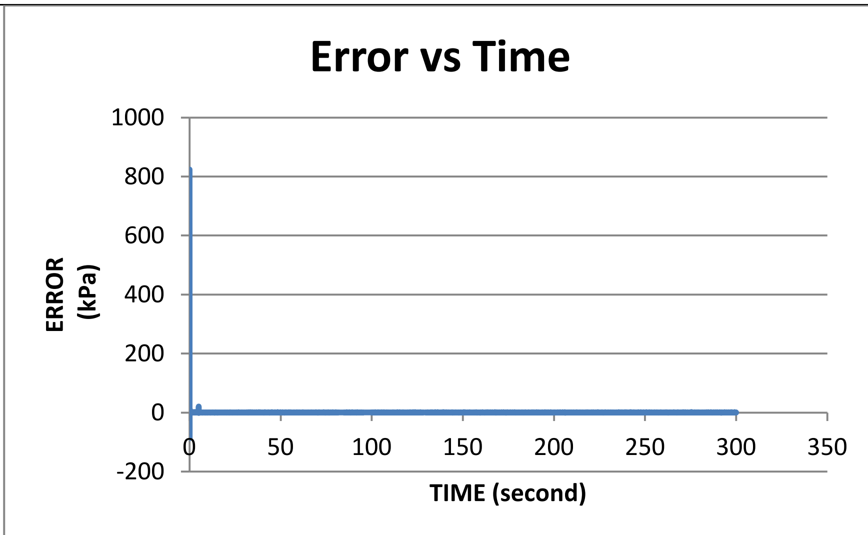
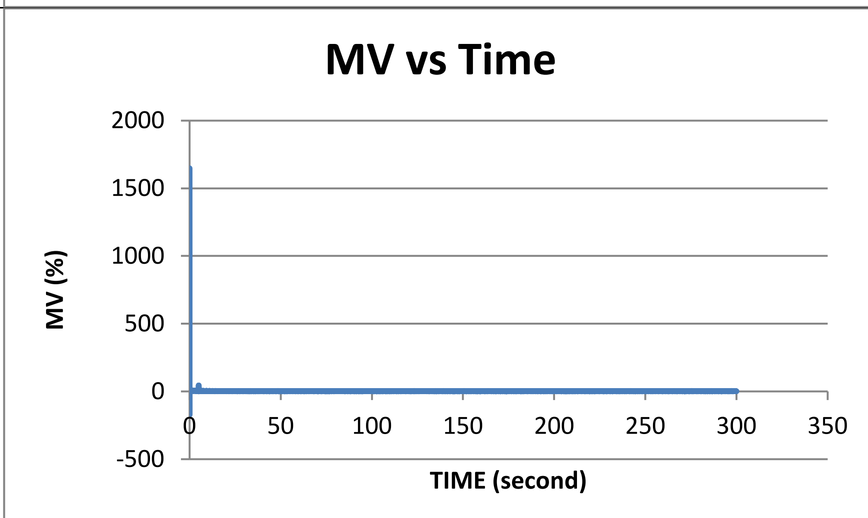
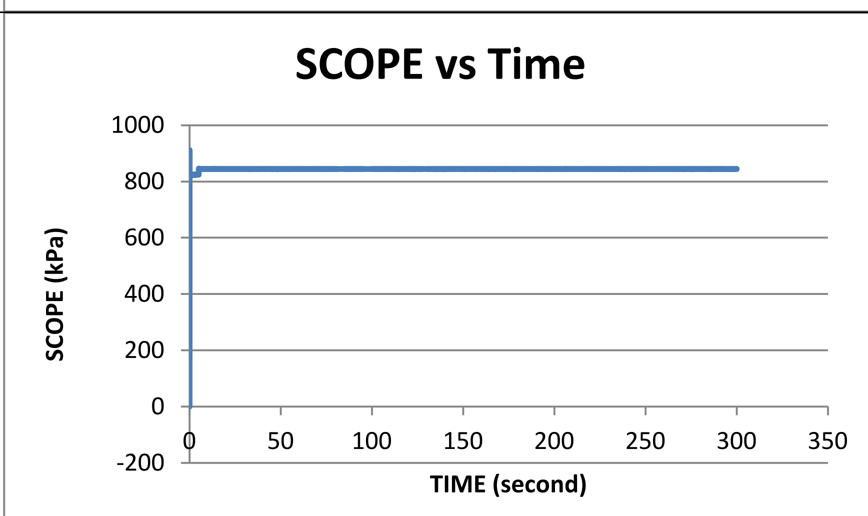
Maintained stable at the beginning and then begin to fluctuate.
</td>
</tr>
<tr>
<td>


</td>
<td>
Maintained stable at the beginning and then begin to fluctuate.
</td>
</tr>
<tr>
<td>


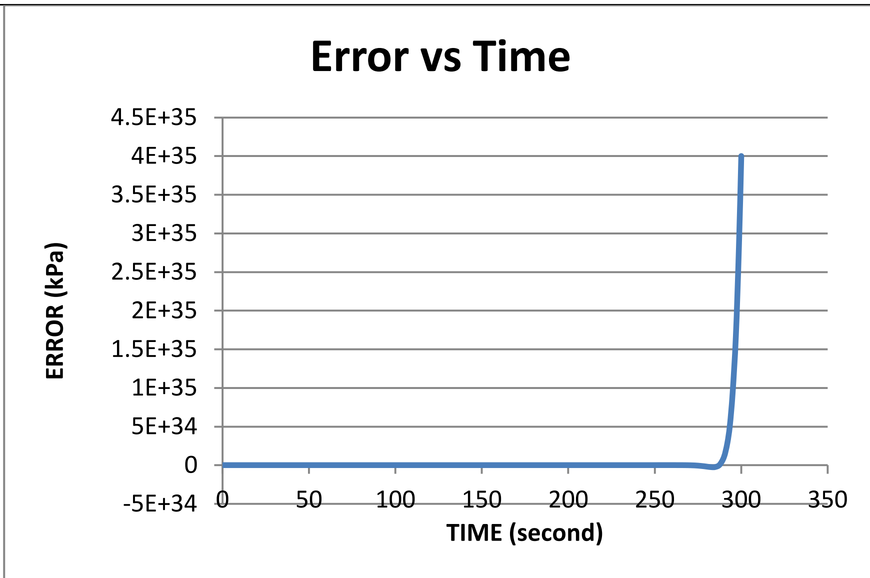
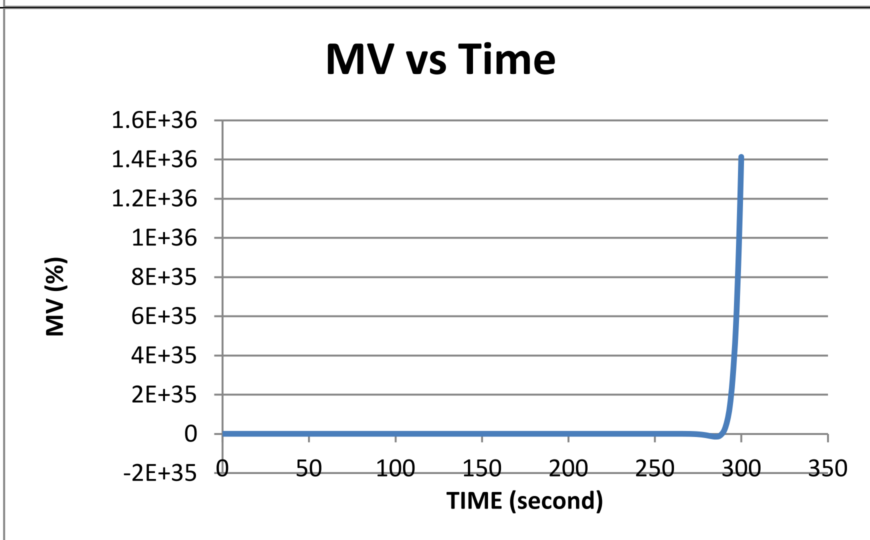
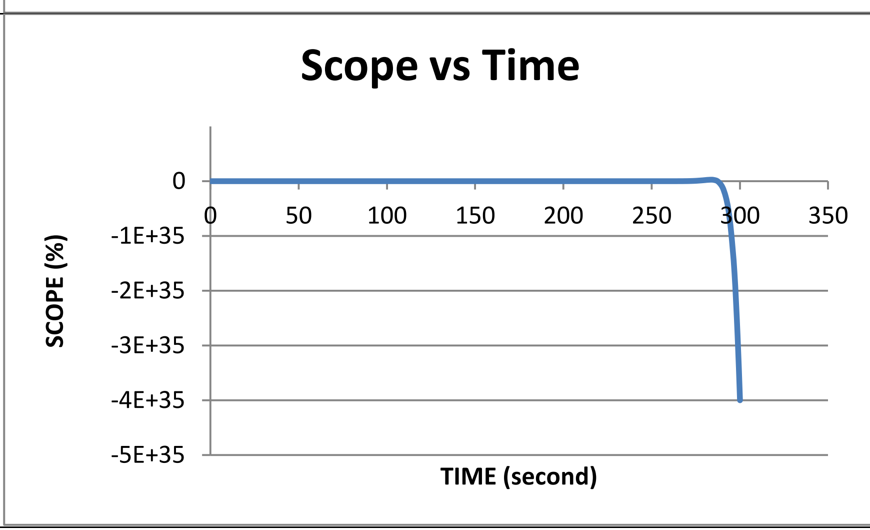
</td>
<td>
Maintained stable at the beginning and then begin to fluctuate.
</td>
</tr>
</table>

7.2.5 PRESSURE 1

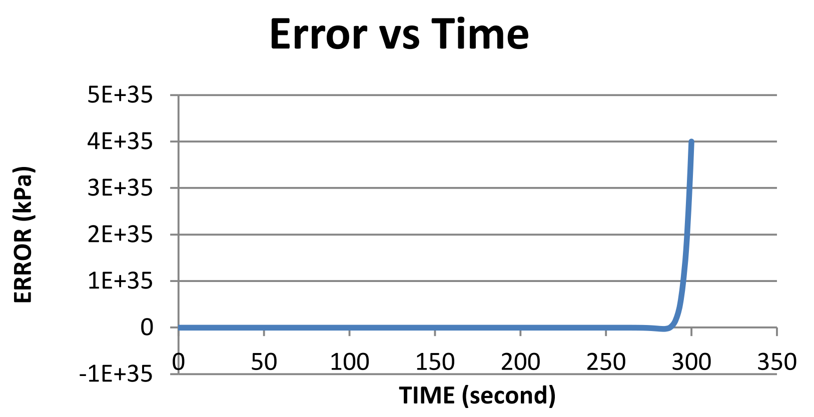
- Cascade Control

<table>
<tr>
<td>
</td>
<td>Area of error =
7.2011
Unstable</td>
</tr>
<tr>
<td>
</td>
<td>Unstable</td>
</tr>
<tr>
<td>
</td>
<td>Unstable</td>
</tr>
</table>

- Feedback Control

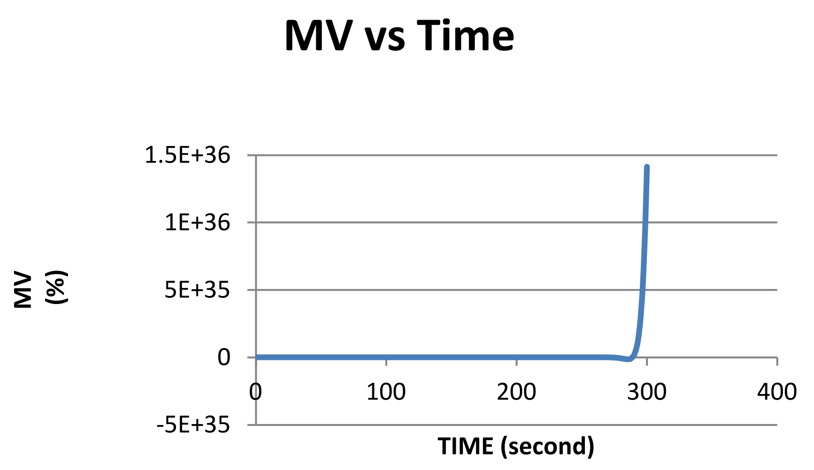
	area = 1.31E+36 Maintained stable and then the value increasing in short time.
	Maintained stable and then the value increasing in short time.
	Maintained stable and then the value decreasing in short time.

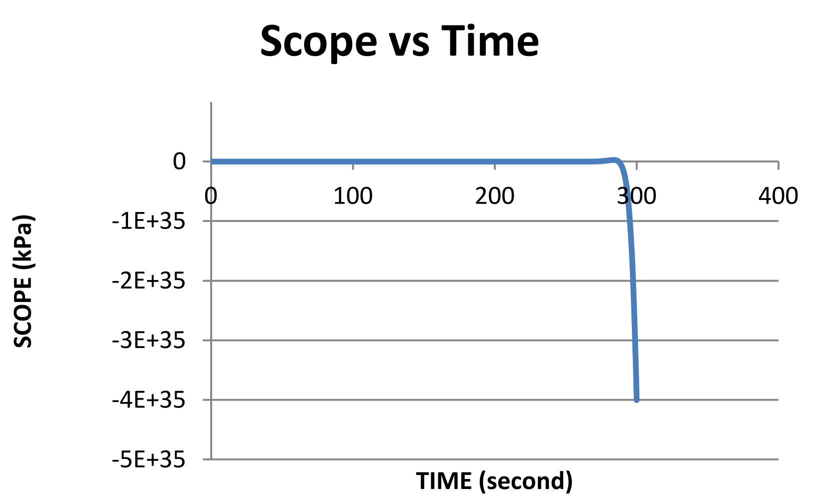
- Feedforward-feedback

<table>
<tr>
<td>


</td>
<td>Area of error =

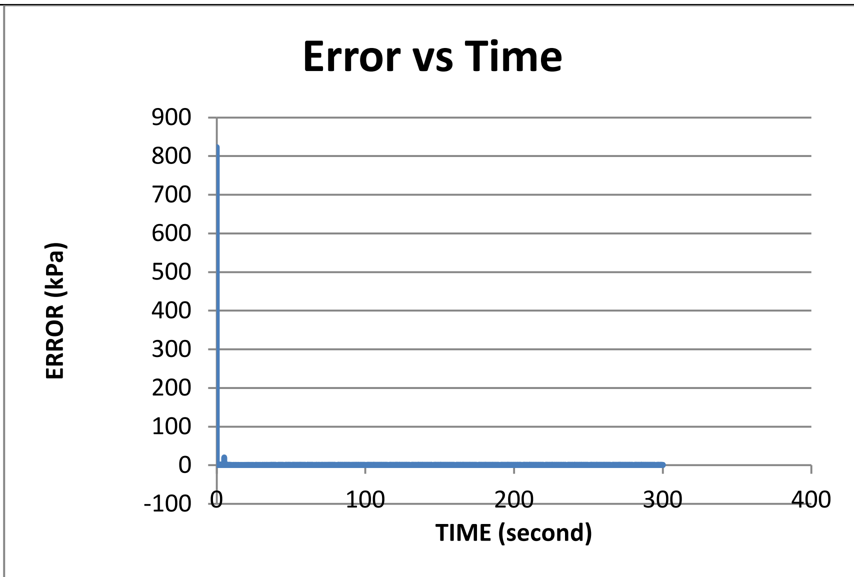
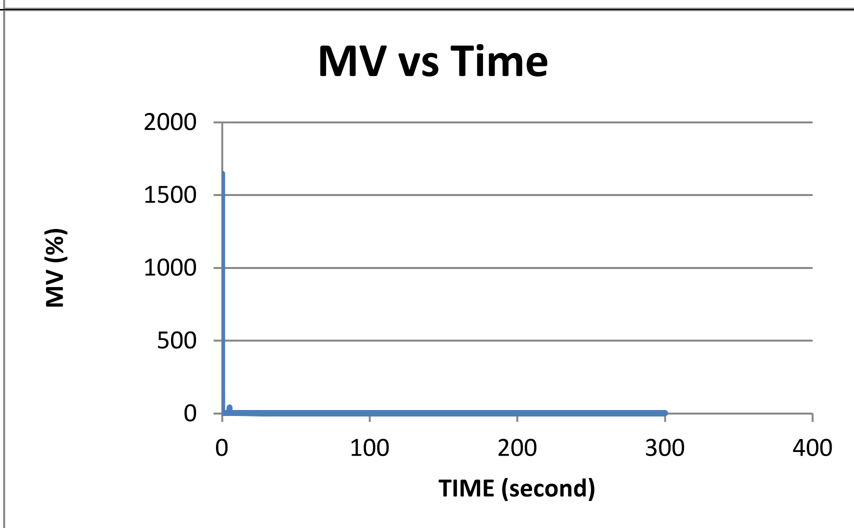
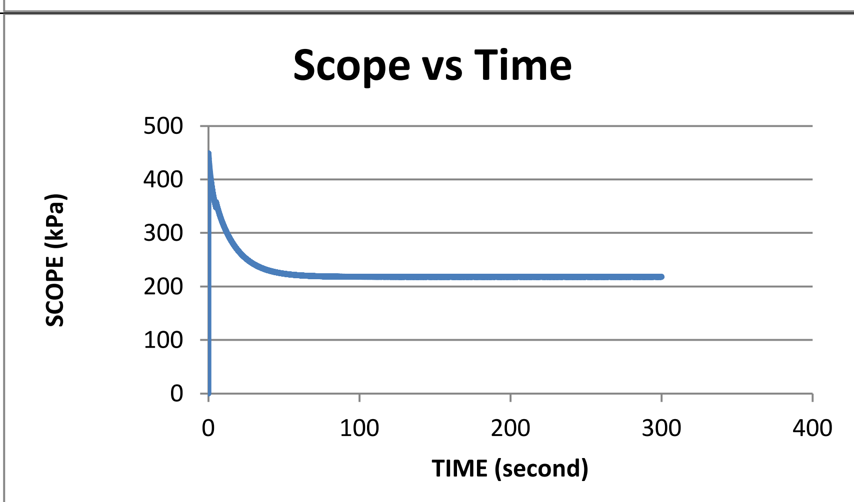
1.31E+36

Maintained stable and then the value increasing in short time.</td>
</tr>
<tr>
<td>


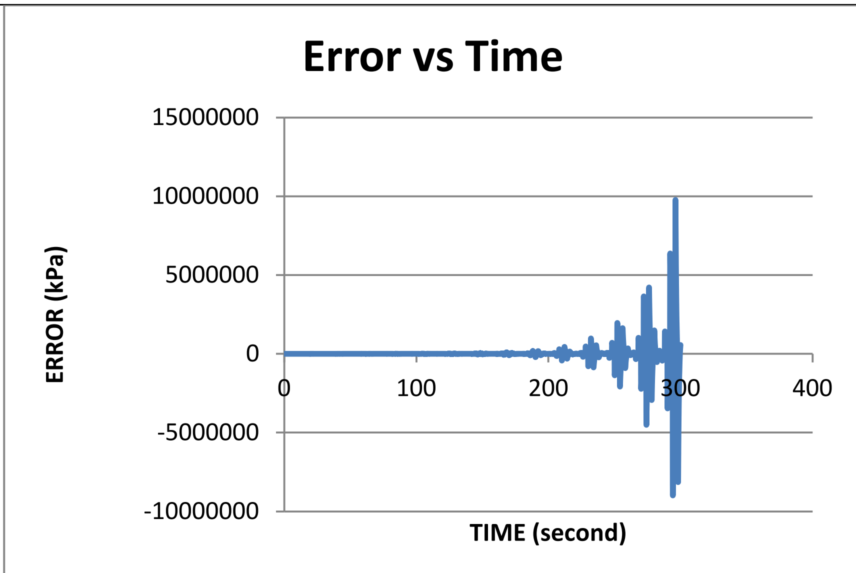
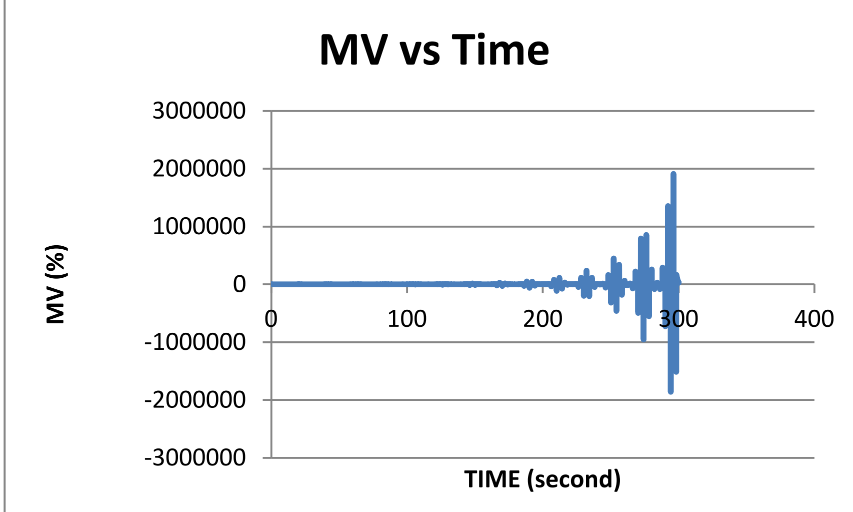
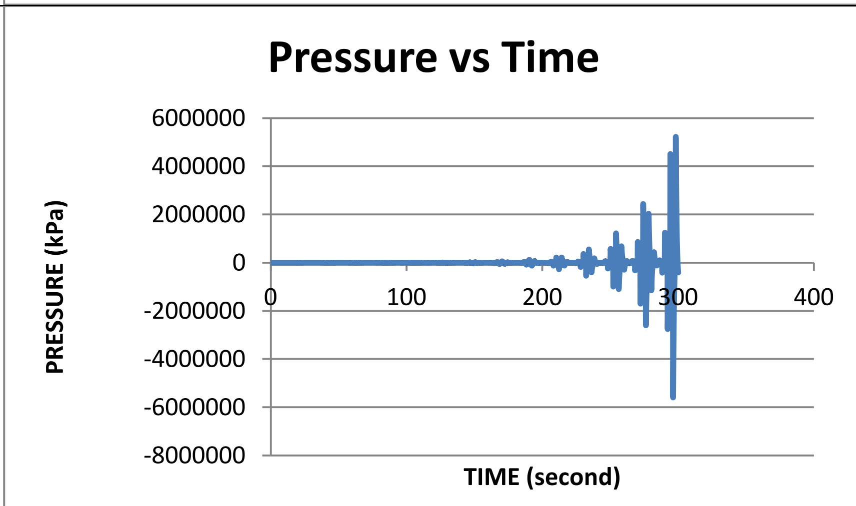
</td>
<td>Maintained stable and then the value increasing in short time.</td>
</tr>
<tr>
<td>


</td>
<td>Maintained stable and then the value decreasing in short time.</td>
</tr>
</table>

- IMC control

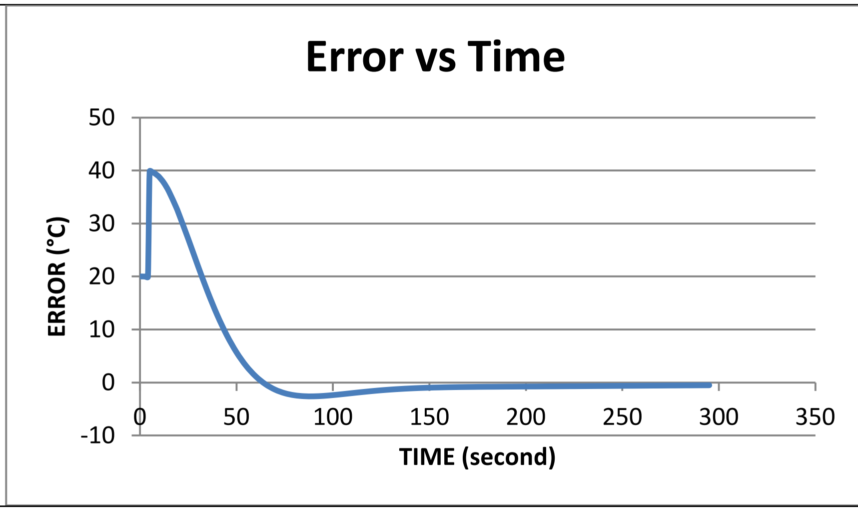
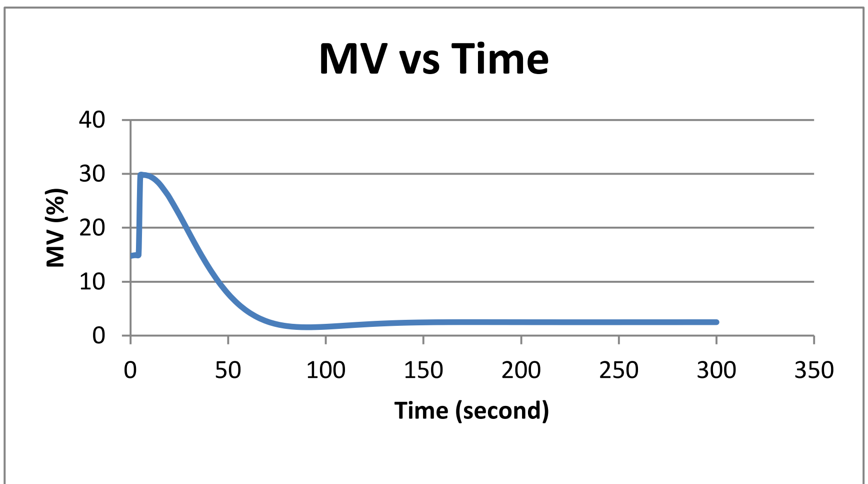
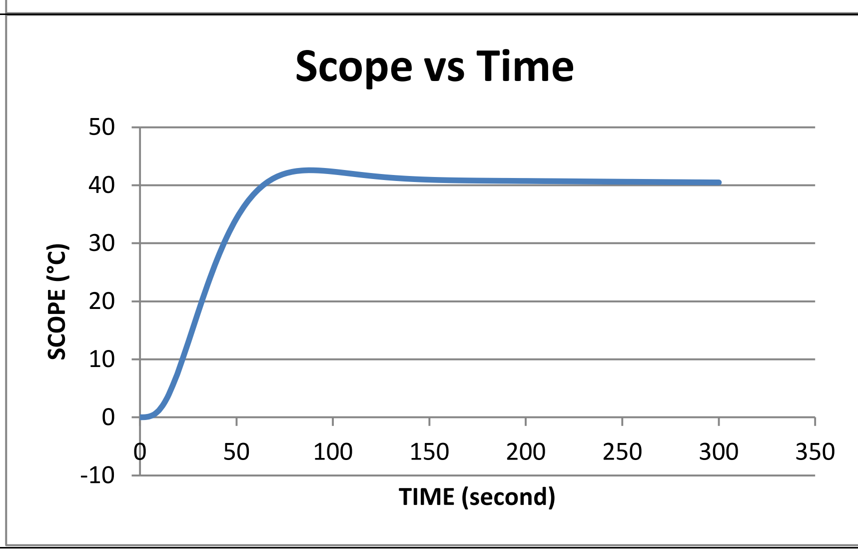
	Area of error = 110.9912 Unstable
	Unstable
	Stable

- Smith Control

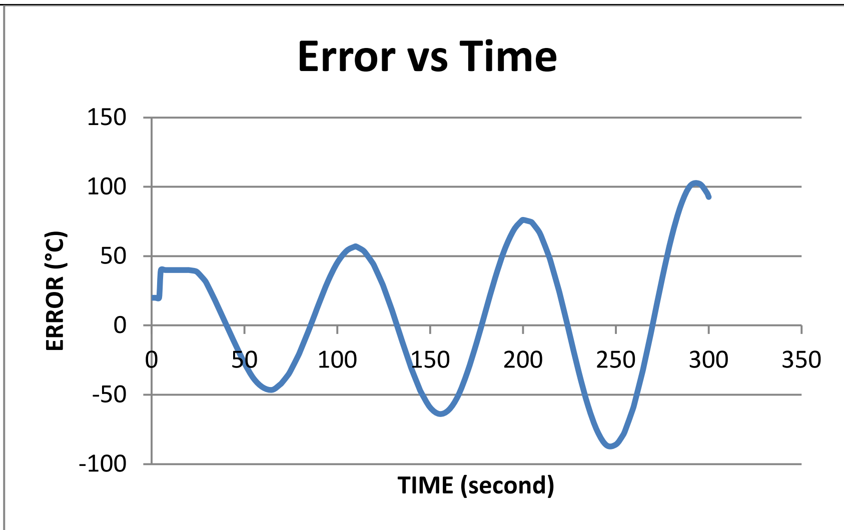
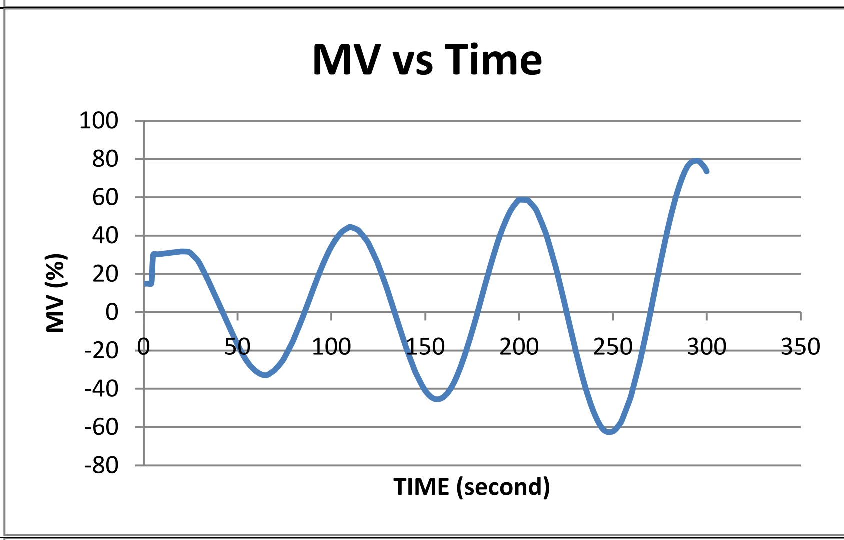
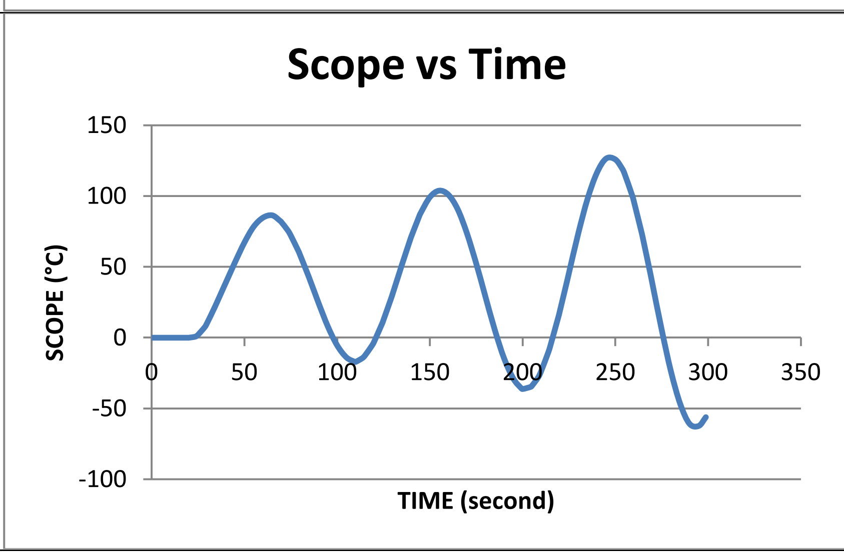
	Area of error = 1.25E+06 Fluctuating and unstable.
	Fluctuating and unstable.
	Fluctuating and unstable.

7.2.6 TEMPERATURE 5

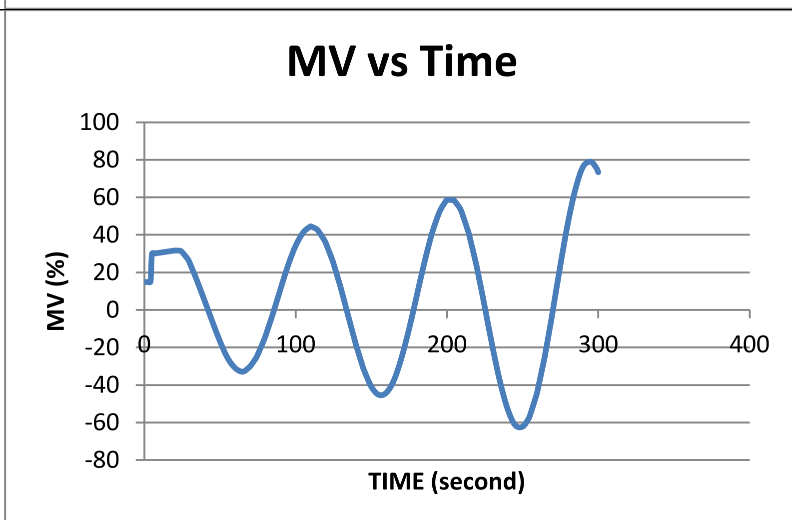
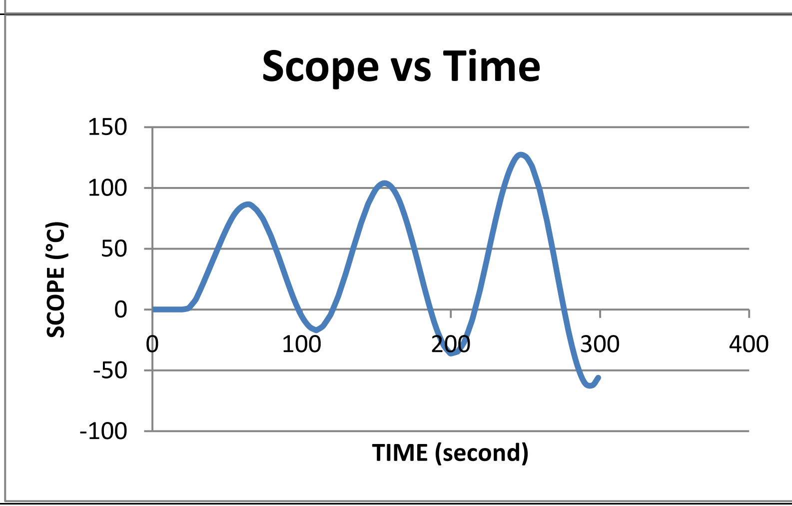
- Cascade Control

	Area of error: 976.72 Stable
	Stable
	Stable

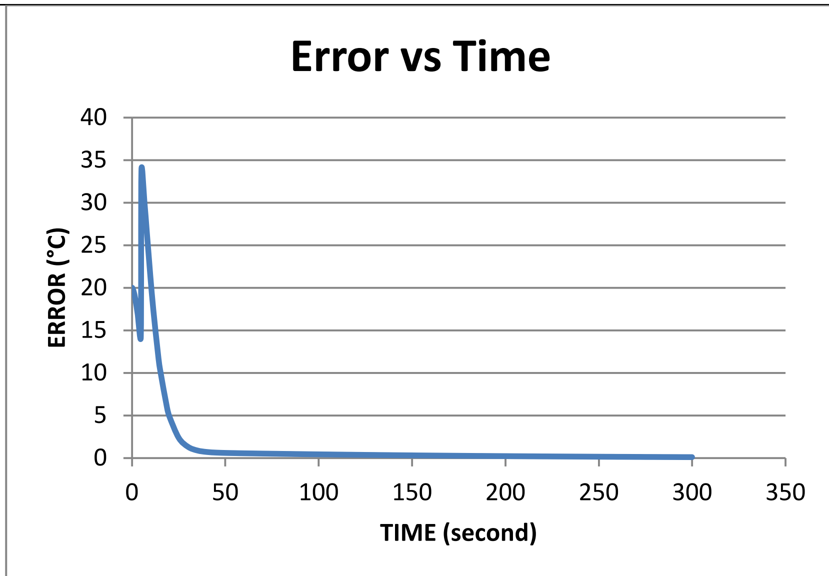
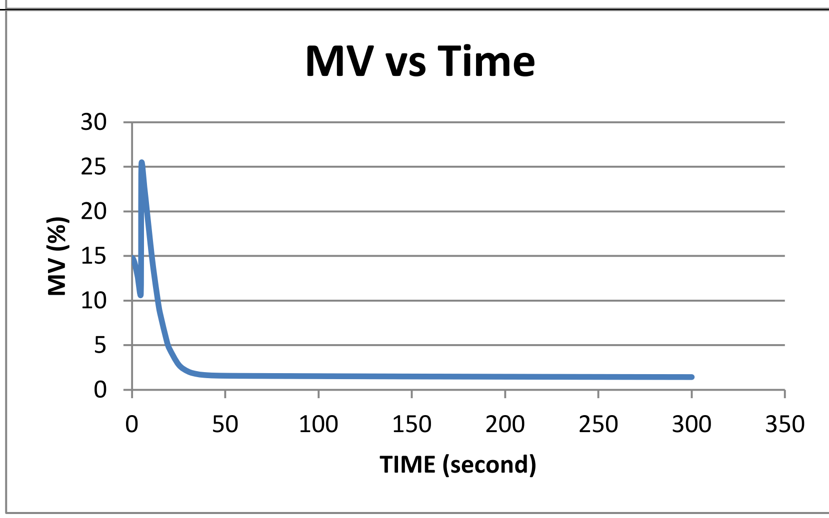
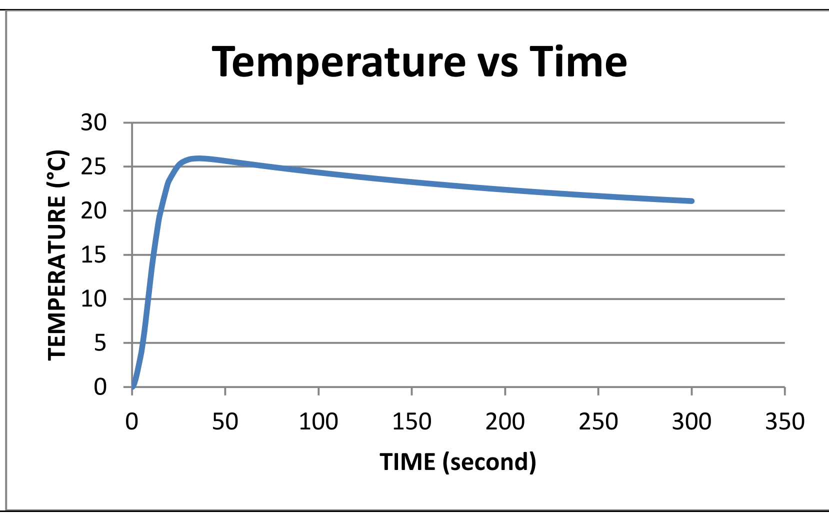
- Feedback Control

	Area of error: 1633.75 Fluctuating and Stable
	Fluctuating and Stable
	Fluctuating and Stable

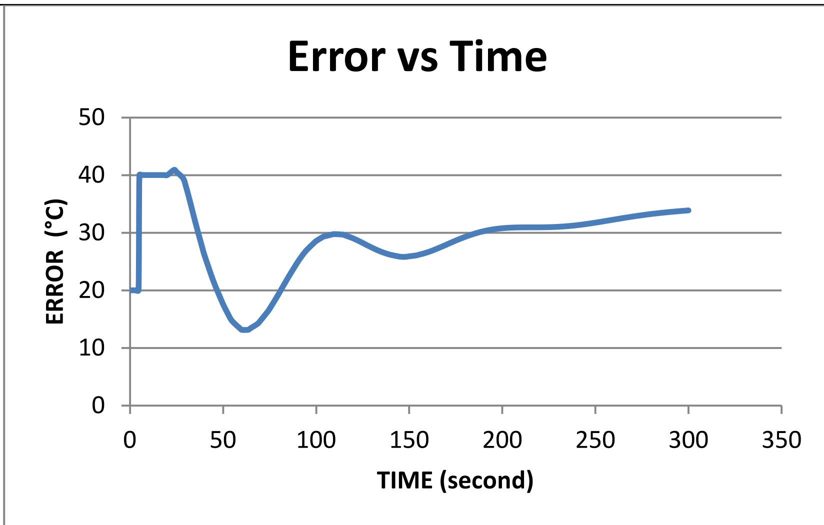
- Feedforward-feedback Control

	Area of error :1633.75 Fluctuating and Stable
	Fluctuating and Stable
	Fluctuating and Stable

- IMC Control

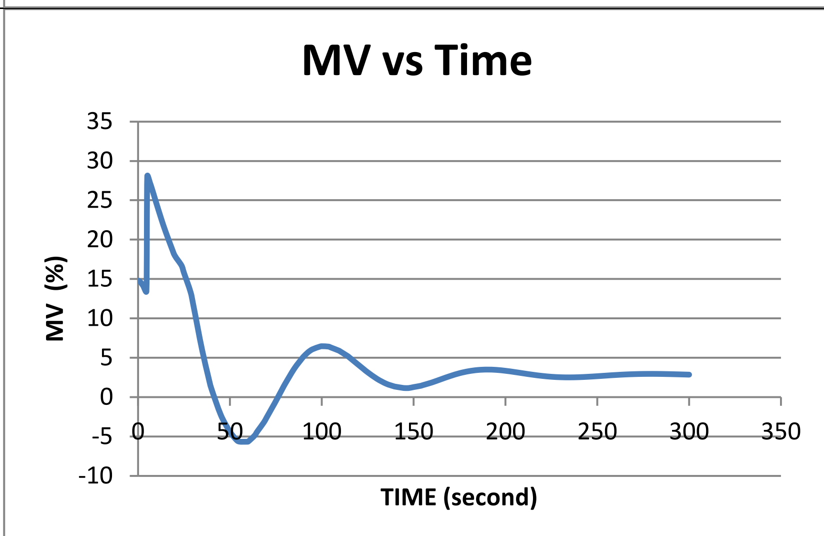
	Area of error: 458.01 Fluctuating at the beginning and then maintained stable.
	Fluctuating at the beginning and then maintained stable.
	Fluctuating at the beginning and then maintained stable.

- Smith Control

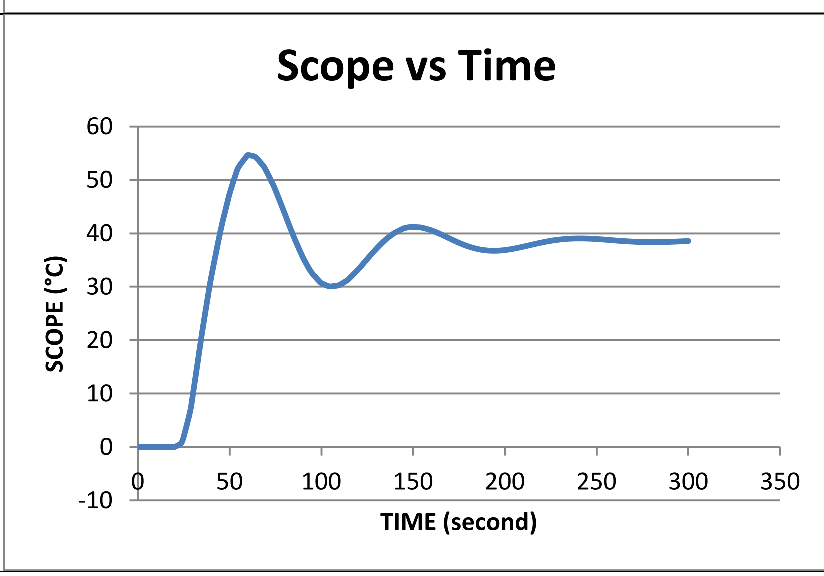


Area of error: 8608.55

Fluctuating at the beginning and then maintained stable



Fluctuating at the beginning and then maintained stable



Fluctuating at the beginning and then maintained stable